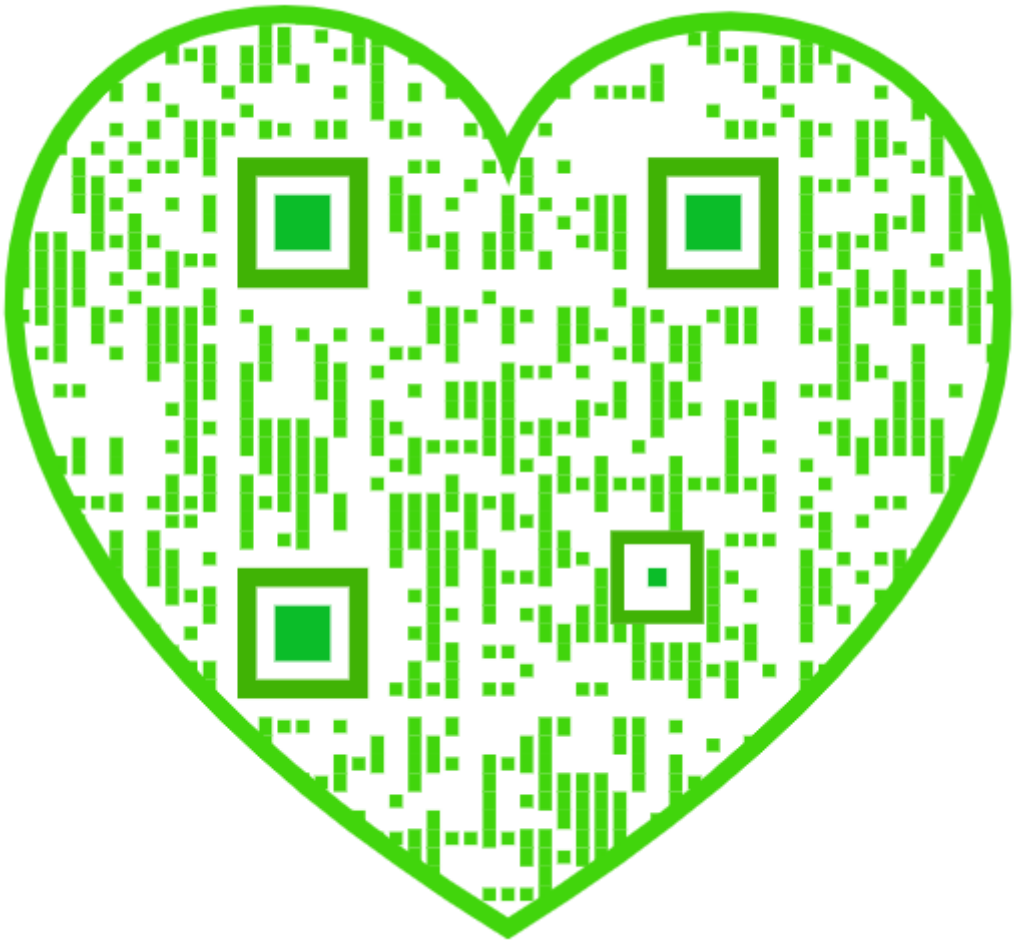
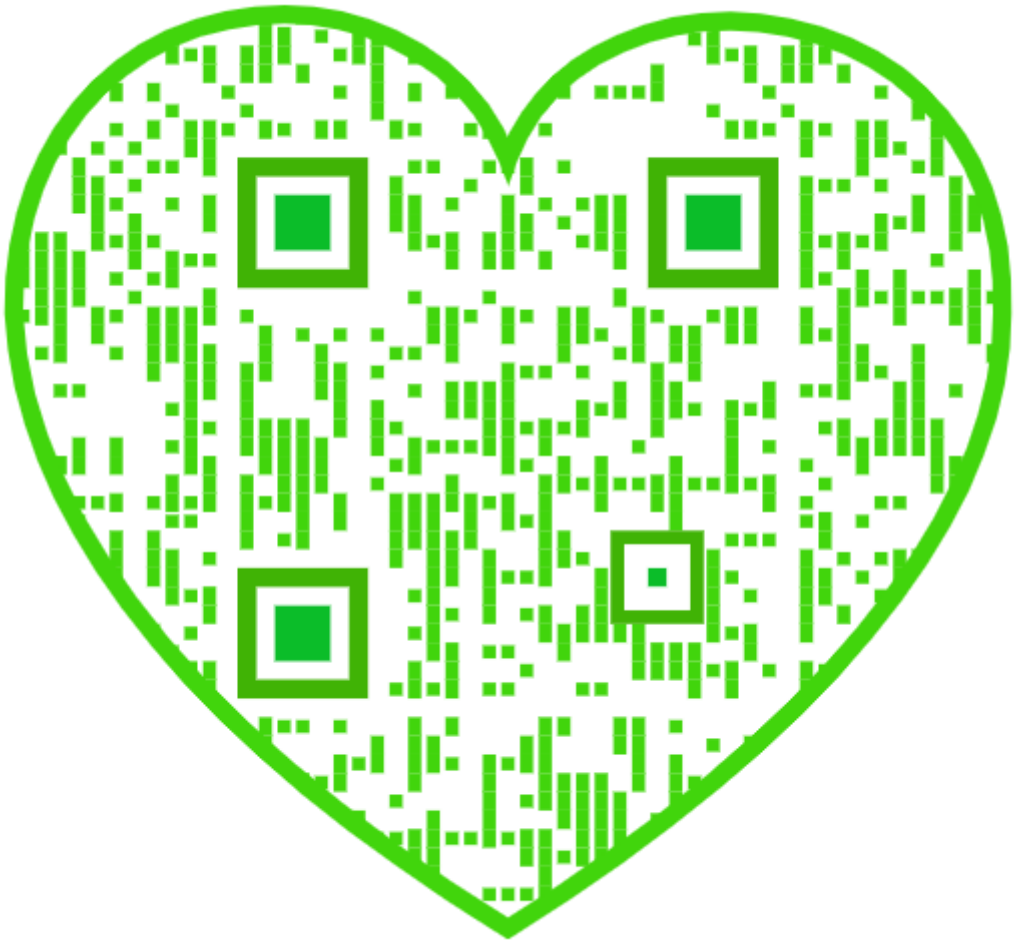
SCHOOL ATLAS
OF
ASTRONOMY
BY
A. KEITH JOHNSTON





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SCHOOL ATLAS

OF

ASTRONOMY

COMPRISING, IN TWENTY-ONE PLATES

A COMPLETE SERIES OF ILLUSTRATIONS OF THE HEAVENLY BODIES

BY

ALEX. KEITH JOHNSTON

LL.D. F.R.S.E. F.R.G.S. F.G.S.

GEOGRAPHER TO THE QUEEN; AUTHOR OF 'THE PHYSICAL ATLAS,' 'THE ROYAL ATLAS,' ETC.

NEW AND ENLARGED EDITION

WITH AN

ELEMENTARY SURVEY OF THE HEAVENS

DESIGNED AS AN ACCOMPANIMENT TO THIS ATLAS

BY

ROBERT GRANT

M.A. LL.D. F.R.S. F.R.A.S.

PROFESSOR OF ASTRONOMY AND DIRECTOR OF THE OBSERVATORY IN THE UNIVERSITY OF GLASGOW

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PREFACE.

IT has long been my opinion that an Atlas of the Heavenly Bodies, uniform in size and style, would form a useful and appropriate addition to my series of Elementary Works on Physical, Classical, and General Geography—an opinion confirmed by many communications from the heads of educational establishments, and others interested in the progress of knowledge. An assurance of the want of a work of the kind led to inquiry as to whether any such existed, and to the conviction that no one, combining elementary facts with scientific precision, had been placed within the reach of the public; hence the only course open to me was to project a new work, suited, as far as possible, to the felt exigency. The subject of each Illustration has been carefully studied, and the details have been worked out at such an expense of time and labour as is seldom bestowed on an elementary work. In illustration of this, it may be noticed that, in the concluding six Maps, the position of every star has been calculated, and its place projected, from the Catalogue prepared under the direction of the British Association for the Advancement of Science, so that the results of that elaborate work are here first produced in a graphic form. It is hoped, therefore, that this Atlas will not only prove useful as an Introduction to Astronomy, but that it will commend itself to the more advanced cultivators of the science.

In the present edition three Illustrations appear for the first time—Plate 13, Meteors; 14, Spectrum Analysis applied to the Sun and Stars; and 21, Ecliptic Charts, representing the apparent paths of the planets Venus, Mars, &c.

Plates 4, 5, 9, and 12 have been re-engraved from new drawings, and the others have been brought up to the present state of knowledge.

The text comprises, in a condensed form, an elementary Survey of the Heavens, in which each figure in the Plates is popularly explained, and the latest facts of the science are presented.

This part of the work is due to Professor Grant, of the Glasgow Observatory.

I take this opportunity of returning grateful thanks to Warren De La Rue, Esq., F.R.S., formerly President of the Royal Astronomical Society of London, who placed at my disposal a valuable series of original photographs, from which many of the new drawings were made; and also to Padre Secchi, the eminent Director of the Observatory of the Collegio Romano, for the instructive photographs representing the Phases of the Moon in Plate 4.

A. KEITH JOHNSTON.

EDINBURGH, *December* 1868.

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ATLAS OF ASTRONOMY.

ELEMENTARY SURVEY OF THE HEAVENS.

CHAPTER I.

General Aspect of the Stellar Heavens—First Results of Observation—Figure of the Earth.

THE heavens, if viewed on a fine night when the sky is free of clouds, present the aspect of an immense hemispherical vault, the concave surface of which is studded with a countless number of luminaries of different degrees of brightness. If the phenomenon be observed for a few hours, it will be found that the stars, like the sun and moon, have a general movement from east to west, ascending above the horizon at different points in the east, and setting beneath the horizon at corresponding points in the west. Like the sun and moon also, the stars attain their highest position above the horizon when they are due south, or on the meridian.

If observations of this kind be prosecuted for several successive nights, it will be found that the stars which sink beneath the horizon in the west reappear on the following night above the horizon in the east, and that the interval of time which elapses between two consecutive appearances of a star in the east, or two consecutive disappearances in the west, is in all cases exactly the same; and this is true in regard to the time which elapses between two consecutive returns of the star to the meridian, or any other determinate point of its course above the horizon. The interval of time in all such cases is, in round numbers, twenty-four hours, as shown by an ordinary clock or watch.

An interesting question which here offers itself is this, What is the time during which a star remains visible above the horizon? The results of observation are in this instance clear and precise. The stars which rise due east set due west, and remain above the horizon twelve hours. The stars which rise to the south of due east, set at corresponding points to the south of due west, and, supposing the observer to be situate anywhere in the northern hemisphere, remain visible above the horizon during less than twelve hours, the interval of visibility gradually diminishing the more nearly the star rises towards the south.

Finally, the stars which rise to the north of due east, set at corresponding points to the north of due west, and dwell above the horizon during a longer period than twelve hours. It

will be found, moreover, supposing the observer to be situated anywhere in the northern hemisphere, that the more towards the north a star rises, the longer it continues visible above the horizon, and that for a certain region of the northern heavens the stars never set at all, but wheel permanently about a fixed point in the celestial sphere.

Another fact of capital importance connected with the phenomena of the stellar heavens is this,—the stars constantly maintain the same position relatively to each other. Thus, if we consider any group of stars—for instance, the well-known group termed the Great Bear—we shall find that, although the stars composing the group vary in position with respect to the horizon when viewed at different times, they always preserve the same mutual configuration. It is for this reason that the general host of the luminaries of the stellar heavens have been denominated *Fixed Stars*, in contradistinction to another class of bodies to be presently referred to, the positions of which in the celestial sphere are continually varying.

The phenomena which we have just described may be accounted for by supposing the stars to be projected on the concave surface of a sphere which revolves uniformly from east to west upon a fixed axis in twenty-four hours. The point around which the stars in the northern heavens revolve is one of the extremities of this axis. In the southern hemisphere an analogous point in the heavens is visible round which the stars perpetually revolve above the horizon. This is the other extremity of the axis of the sphere.

A few of the luminaries of the stellar sphere are found not to conform to the foregoing general description. If we fix our attention on certain of the brighter stars, they will be seen to be continually changing their positions with respect to the other stars. At one time they are seen travelling from west to east, or in the direction contrary to that of the diurnal motion of the sphere. At other times they appear to travel in the opposite direction, or from east to west. On the whole, however, their eastward motion exceeds their westward motion, and the result is that they ultimately make the complete tour of the heavens in the direction opposite to that of the diurnal motion of the sphere; then they recommence their courses anew, and pursue the same cycle of changes as before. Bodies of this class are termed *planets*, the appellation being derived from a Greek word which signifies *to wander*. The time of completing the tour of the heavens is found to be different for each planet.

Observation shows that the sun and moon also have a motion among the stars, in virtue of which they accomplish the circuit of the celestial sphere, the former in a year, the latter in somewhat more than twenty-seven days. We shall hereafter give more precise details on this head.

Before proceeding to give some description of the general theories which have been propounded with the view of accounting for the various phenomena of the heavens, it will be desirable to consider briefly the shape of the body from the surface of which our observations are made.

Various circumstances concur in proving that the earth is a body of a round or globular figure. Thus, let us consider the case, so frequently cited, of the appearance presented by a ship proceeding out to sea. The different parts of the vessel do not all fade simultaneously into indistinctness from mere distance. On the contrary, the hull of the vessel first disappears, then the lower parts of the rigging, and finally the top of the masts. Now this is exactly the succession of appearances which would be presented if the earth was a round or spherical body.

Again, it is well known that lunar eclipses are occasioned by the moon entering into the shadow which the earth forms by its interception of the sun's rays. Now it has been observed that in all such phenomena the outline of the shadow is circular. This result;

however, can only be explained by the supposition of the earth being a body having the shape of a sphere. Indeed, the figure of the earth is indicated so palpably by observations, even of the most rudimentary kind, that it was known to the Greeks from the earliest ages of their astronomical history.

CHAPTER II.

Ancient Notions respecting the Movements of the Heavenly Bodies— Copernican System of the Universe.

Although the nations of Western Asia observed the phenomena of the heavenly bodies from a very remote antiquity, they do not appear to have ascended to any general views respecting the system of the universe. It is to the astronomers of ancient Greece that we owe the earliest advances made in this respect. According to the system most generally prevalent among them, the earth was supposed to be placed immovable in the centre of the universe, while the sun, moon, and planets revolved around it in orbits of different magnitudes. The vicissitudes of day and night were explained by a revolution of the entire celestial sphere round the earth once in every twenty-four hours.

This system is generally denominated the Ptolemaic system of the universe, because it was adopted and expounded by Ptolemy, one of the most eminent astronomers of antiquity; but it is in reality of much earlier origin than the time of Ptolemy. It continued to form the basis of all astronomical researches down to the sixteenth century, when the true system of the universe was finally propounded in all its completeness by the immortal Copernicus.

It is a remarkable fact that several of the philosophers of ancient Greece were led to adopt views respecting the system of the universe which have subsequently been found to accord with the true state of nature. Their ideas, however, did not extend beyond the region of mere conjectural hypotheses, and they consequently failed to exercise any influence on the progress of astronomical inquiry.

It is said that Copernicus was originally led to entertain doubts respecting the Ptolemaic system of the universe, by his observations of the appearance presented by the planet Mars in different parts of its orbit. At one time the planet appeared almost as bright as Jupiter; at other times its light was so faint that it scarcely surpassed a star of the fourth magnitude. From this fact Copernicus concluded that it was impossible the earth could be the centre round which the planet revolved. Pursuing the train of his ideas, he was led to ponder on a statement contained in the works of some ancient writers, to the effect that the Egyptians supposed the planets Mercury and Venus to revolve round the sun, while they at the same time accompanied it in its annual motion round the earth. Again, some of the philosophers of ancient Greece supposed the sun to be in the centre of the planetary system, while the earth revolved in an annual orbit around it. Others of them, again, maintained that the diurnal revolution of the starry sphere was a mere illusory phenomenon occasioned by the revolution of the earth upon an axis in the opposite direction. Meditating upon these ideas and others of a similar kind, rejecting what was improbable, and adopting what appeared to him to be consonant to the simplicity of nature, he finally was led to propound the system which bears his name, and which has been universally adopted by the astronomers of modern times.

According to Copernicus, then, the sun is placed in the centre of the universe, while the

planets, including the earth, revolve around it in orbits of different magnitudes. The order of succession of the planets, proceeding outwards from the sun, is this,—Mercury, Venus, the Earth, Mars, Jupiter, and Saturn. These were the only planets known in the time of Copernicus. Placed at an inconceivable distance from the solar system was the sphere of the fixed stars. The moon was supposed, as in the ancient system, to revolve in a monthly orbit around the earth. The diurnal motion of the stars from east to west was accounted for by attributing to the earth a rotatory motion on a fixed axis in the opposite direction, or from west to east, the axis being inclined to the plane of the earth's orbit at a certain definite angle.

CHAPTER III.

Explanation of the principal Circles of the Celestial Sphere — Determination of the Position of an Object by its Right Ascension and Declination; also by its Longitude and Latitude — Determination of the Position of a Place on the Earth's Surface.

This chapter will be devoted to an explanation of certain terms used in astronomy, and a description of the methods commonly employed by astronomers for fixing the position of an object in the celestial sphere.

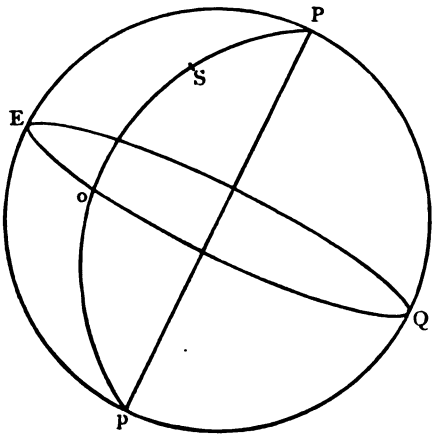
The results of direct observation, as already remarked, indicate that the stars apparently revolve with a common angular motion round a fixed axis of the celestial sphere. The great circle of the sphere, which is perpendicular to this axis, is termed *the equator*. The extremities of the axis are termed *the poles*. Of these the pole which is elevated above the horizon in the northern hemisphere is termed *the north pole;* the other is termed *the south pole*, and is elevated above the horizon of any place in the southern hemisphere. It is obvious that when the north pole is elevated above the horizon, the south pole is depressed beneath it, and *vice versâ*. The stars, in virtue of their apparent diurnal motion, generally revolve in imaginary small circles of the sphere, parallel to the equator. The apparent path which the sun annually describes in the heavens is termed *the ecliptic*. Like the equator, the ecliptic is a great circle of the celestial sphere. A diameter of the sphere, drawn perpendicular to the plane of the ecliptic, is termed the axis of that circle, and the extremities of this axis are termed the poles of the ecliptic. The equator and the ecliptic are inclined to each other at a certain definite angle. This angle is denominated *the obliquity of the ecliptic*. Its magnitude amounts in the present day to 23° 27′ 5.″5, but it is diminishing from age to age, although with excessive slowness. In the beginning of this century, which is an epoch frequently employed in astronomical computations, it amounted to 23° 27′ 55″. The small circles drawn parallel to the equator, at the points where the ecliptic recedes most from the plane of that circle, are termed *the tropics*. The tropic of the northern hemisphere is termed *the Tropic of Cancer*. The tropic of the southern hemisphere is termed *the Tropic of Capricorn*. It will be seen that the equator and the ecliptic intersect each other in two opposite points of the sphere. One of these points, the point in which the sun is situate when it is passing from the south to the north of the equator, is termed *the first point of Aries*. The origin of this designation will be explained hereafter.

The earth may be considered as a sphere concentric with the celestial sphere, and having

analogous circles described upon its surface. The circles of the celestial sphere refer merely to apparent movements; the analogous circles of the earth have reference to the real movements of that body. The same remark applies to analogous diameters of the two spheres. Thus the diameter of the terrestrial sphere passing through the north and south poles indicates the axis around which the earth *really* revolves; the same axis, when prolonged to the heavens, becomes the axis of the celestial sphere, or the axis round which the stars *apparently* revolve. Similarly, the plane of the terrestrial equator, when extended to the heavens, traces out the celestial equator.

The various explanations which we have given here will be better understood by referring to fig. 1, Plate 1, but the student will find it to his advantage to consult carefully the circles described upon a celestial globe, and also those on a terrestrial globe.

An important part of astronomy consists in determining the positions of objects in the celestial sphere. Generally the position of a point on a spherical surface is ascertained when we know its angular distance from two great circles of the sphere whose planes are perpendicular to each other. Let P p represent the axis of the celestial sphere, P the north, p the south pole, E Q the equator, P E p Q a great circle passing through the poles, and meeting the equator in the points E, Q, where the ecliptic and the equator intersect each other. Let S represent the place of a star in the celestial sphere, and let P S p denote a great circle passing through the poles and the star. Finally, let us suppose E to represent the first point of Aries, as already defined. The circle P E p Q is termed the equinoctial colure. Now, if we



assume as our circles of reference, the equator and the equinoctial colure, the position of the star S in the celestial sphere will be definitely fixed by means of its measured angular distance from those circles; in other words, by means of the arc E o and the arc S o. The arc E o is termed the right ascension of the star; it obviously measures the angle contained between the equinoctial colure and the great circle passing through the star. The arc S o is termed the declination of the star. Thus the position of an object in the celestial sphere is ascertained when we know its right ascension and declination.

If we had used for the circles of reference the ecliptic and a great circle passing through its poles and the first point of Aries, the position of the star would be determined by its distance from the first point of Aries, measured on the ecliptic, and its distance from the ecliptic,

measured upon a great circle passing through the poles of the ecliptic and the star. The former of these elements is termed the longitude of the star, the latter is termed the latitude. It was in this form that the ancient astronomers represented the position of an object in the celestial sphere.

Similarly the position of any place on the earth's surface is determined by means of its distance measured with respect to two great circles of the sphere perpendicular to each other. In this case the two reference circles are the equator, and a great circle passing through the poles, or a meridian, as such a circle is usually called. The distance from the equator is termed the latitude of the place; the distance from the meridian is termed the longitude. The equator has a determinate position on the earth's surface. It is otherwise with the meridian, of which any number may be drawn on the surface. Generally each nation uses for this purpose the meridian which passes through its capital city. Thus the longitudes of places in the British Isles are measured from the meridian of Greenwich; in France, the meridian of Paris is used for a similar purpose,—and so with other countries.

CHAPTER IV.

Measurement of Time—Apparent Motion of the Sun used for this purpose—Apparent Solar Time—Mean Solar Time—Sidereal Time—Equation of Time.

One of the most important practical advantages connected with the study of astronomy consists in its supplying us with an invariable standard for the measurement of time. In all civilised countries the subdivision of time is regulated mainly by the sun, the apparent motion of which exercises so important an influence on the daily concerns of life. And yet at first sight the sun would seem to be most unsuitable for this purpose. If we were to measure the length of the day by the time during which the sun is above the horizon, no standard could be more fallacious. In winter the days are short, in summer they are very long; in fact, throughout the whole year they are perpetually varying from day to day. In this respect the sun presents a striking contrast to the stars, the duration of whose respective courses above the horizon is invariable.

But let us take a more general view of the subject. Let us define the solar day to be the interval which elapses between two consecutive returns of the sun to the meridian. In this case again we encounter perpetual variations, although not so extensive as in the former instance. The length of the day thus defined does not deviate throughout the year to the extent of more than half a minute from the mean or average length of the days in the year. The mean solar day is on this ground used as the fundamental unit for the measurement of time. Each day is subdivided into twenty-four hours, each hour into sixty minutes, and each minute into sixty seconds. In this way we obtain days, hours, minutes, and seconds of mean solar time.

The day, as defined by the interval of time which elapses between two successive returns of the real sun to the meridian, is denominated the apparent solar day, in contradistinction to the mean solar day, which is the average of all the apparent solar days in the year. Similarly the time which elapses between two successive returns of a star to the meridian is termed a sidereal day. This interval of time, like the mean solar day, is invariable, and is in like manner subdivided into hours, minutes, and seconds.

In general the sidereal day is shorter than the solar day. The reason of this is obvious. It arises from the circumstance of the annual motion of the sun being contrary in direction to the diurnal motion of the stars. Let us suppose the sun and a star to be upon the meridian at the same time. After the lapse of a sidereal day the star will again have returned to the meridian; but the sun, in virtue of its annual motion, will have travelled somewhat to the eastward during the intermediate period, and an additional short interval of time must elapse before it is again transported to the meridian by the diurnal motion. If we suppose the mean solar day to consist of twenty-four hours, the sidereal day will be found to number 23 hours, 56 minutes, 4 seconds of mean solar time. The sidereal day is therefore shorter than the mean solar day by 3 minutes 56 seconds.

It has been already stated that the standard of time by which ordinary clocks and watches are regulated is the mean solar day. If we suppose a fictitious sun to travel eastward in the celestial equator with a uniform motion, and to perform a complete revolution in a solar year, the interval between two successive arrivals of such a sun on the meridian will be a mean solar day, and its presence on the meridian will determine the instant of mean noon, as shown by an accurately going clock or watch. Time-keepers which are regulated by the annual motion of this fictitious or mean sun are said to indicate mean solar time.

Apparent noon is determined by the instant when the real sun appears on the meridian. Since the interval between two successive returns of the real sun to the meridian is perpetually varying throughout the year, it is obvious that the instant of *apparent noon* will generally differ throughout the year from the instant of *mean noon*, as determined by the interval between two successive arrivals of the fictitious or mean sun on the meridian. This difference between the instant of apparent noon and the instant of mean noon is termed by astronomers *the equation of time*. Its value for every day in the year is given in the 'Nautical Almanac.' It manifestly enables us to pass from apparent to mean noon, and *vice versâ*.

Apparent time coincides with mean time on four days in the year—viz., April 15, June 14, August 31, December 24. On those days the sun arrives on the meridian at mean noon —in other words, at twelve o'clock, as shown by an ordinary clock or watch. It is also obvious that a sun-dial, which usually indicates apparent time, will at once give the true time on any of the four days just mentioned. On any other day of the year it will be necessary to apply the equation of time to the indications of the dial, so as to pass from apparent to mean solar time.

It has been stated that on four days of the year apparent time coincides with mean time; in other words, the sun is on the meridian at the instant when the clock shows twelve. On every other day of the year the clock is either *before* the sun or *behind* the sun; or, which amounts to the same thing, when the clock shows the instant of noon, the sun either has not come to the meridian or has already passed the meridian. The following illustration will make this more clear.

On January 1, 1869, the clock is 3 minutes 58 seconds *before* the sun. This indicates that when the sun is actually on the meridian, the clock ought to show oh. 3m. 58s. The sun continues to fall behind the clock till February 11, when the difference between them amounts to 14 minutes 29 seconds. Henceforward the sun gains daily upon the clock until April 15, when they coincide, and the equation of time vanishes. From this day the clock is *behind* the sun, the difference attaining its maximum on May 14, when it amounts to 3 minutes 53 seconds—that is to say, when the sun is on the meridian the clock ought to show 11h. 56m. 7s. The sun now begins to fall back relatively to the clock, and the difference between them continues to diminish until June 14, when they finally coincide again. From this day the clock is again *before* the sun, the difference attaining its maximum on July 26, when it amounts

to 6 minutes 14 seconds. From July 26 the sun continues to gain upon the clock until August 31, when the difference between them vanishes, and apparent time coincides again with mean time. From August 31 the sun gains upon the clock, or the clock is *behind* the sun, the difference attaining its maximum on November 3, when it amounts to 16 minutes 18 seconds. Henceforward the sun begins to fall behind, and this goes on until December 24, when apparent time again coincides with true time. From December 24 the clock begins to be *before* the sun, the difference on December 31 amounting to 3 minutes 23 seconds. On January 1, 1870, the same cycle of changes commences, and is repeated in the ensuing year.

The difference which generally exists between apparent and true time arises from two distinct causes—the variable motion of the sun in its orbit, and the inclination of its path to the equator. If only one of those causes acted, or if both causes were synchronous in their action, there would be only one period in the year during which the clock was *before* the sun, and only one period during which it was *behind* that body. But the times of maximum and minimum action of both causes being different, there hence originate two periods of each kind in the course of the year.

We have supposed, in the foregoing explanation, that true or mean time is obtained solely by observations of the sun. First, we determine the instant of apparent noon by observing the sun when it is on the meridian, and then, by means of the equation of time, we pass from apparent to mean noon. It may be well to state, however, that true time is generally ascertained at astronomical observatories, not by the sun, but by the stars. There are several important reasons in favour of this course of procedure. First, the sun appears on the meridian only once in twenty-four hours, and at the instant of arrival its disc may be obscured by clouds. On the other hand, the stars are dotted over the whole heavens, and the astronomer consequently, by availing himself of them, is more independent of temporary casualties of the weather. He is also enabled, by observing the transits of several stars over the meridian on the same night, to arrive at a more accurate result as regards the determination of the true time than if he depended upon the observation of only one object. Again, the instant of a star's passage across the meridian may be observed with much greater precision than the instant of the sun's passage. It is true that the observation of a star supplies us only with sidereal time, but the results in the 'Nautical Almanac,' founded upon the theory of the sun's apparent motion, enables us to pass with facility from sidereal to mean solar time.

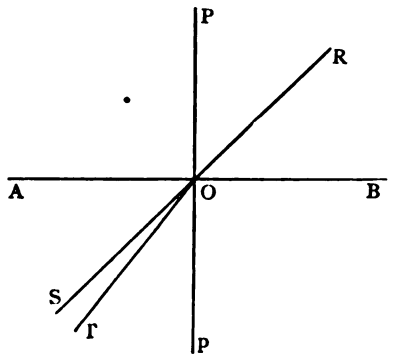
CHAPTER V.

On the Corrections to the Apparent Position of a Celestial Object—Refraction—Aberration—Precession—Nutation—Parallax.

The basis of every theory relating to the movements of the heavenly bodies, consists in accurate determinations of their apparent positions made at well known times with instruments constructed for the purpose. But there are certain disturbing causes which exercise an influence on the apparent position of an object in the celestial sphere, the effects of which must be carefully eliminated before the results thus derived from observation can be available as materials for any ulterior researches relating to the advancement of astronomy. We may enumerate these disturbing influences thus,—Refraction, Aberration, Precession, Nutation, Parallax. They

are usually termed *corrections* to the observed position of a celestial object, because, in all instances wherein they are of sensible magnitude, it is necessary to correct the observed position of the celestial object by eliminating from it the effects which they severally produce. We proceed to make a few remarks on each of these corrections.

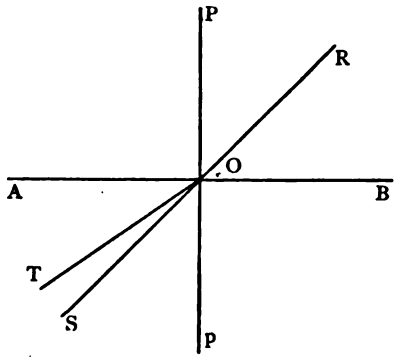
Refraction.—When a ray of light passes from a rarer into a denser medium—as, for instance, from air into water—it invariably undergoes a change of direction. Thus, let R O represent



a ray of light emanating from an object at R, and encountering at O a medium of greater density than that through which it previously passed. Let A B be the surface which separates the rarer from the denser medium, and let P p be a perpendicular to this surface. If the ray, after passing O, had continued to traverse a medium of the same density, as in the first instance, it would have proceeded to S in a line coincident with its original direction. In consequence, however, of its passage from a rarer into a denser medium, its course is bent at O, and the result is that it now takes up a new course, O T, *nearer* to P p than O S is. This phenomenon is termed *Refraction.*

The angle R O P, which the incident ray makes with a perpendicular to the surface bounding the two media, is termed the angle of incidence; the angle T O p, which the refracted ray makes with the same line P p, is termed the angle of refraction. It is obvious that in all cases of the passage of a ray of light from a rarer into a denser medium, the angle of refraction is *less* than the angle of incidence.

When a ray of light passes from a denser into a rarer medium, the effect produced upon



its course is the reverse of what occurs in the former instance. Thus, if we suppose the ray R O to pass from a denser into a rarer medium at O, its subsequent course O T

will be farther removed from the perpendicular P p than O S, the line which marks the direction of its original course. In this case the angle of refraction is manifestly *greater* than the angle of incidence.

The law of refraction, whether it relates to the passage of a ray of light from a denser into a rarer medium or *vice versâ*, is usually enunciated in the following terms: *The sine of the angle of refraction is proportional to the sine of the angle of incidence.*

The rays of light from a celestial object necessarily undergo refraction in passing through the atmospheric fluid which encompasses the earth. In this case, however, the medium through which the rays pass being composed of concentric strata of different densities, the course of the refracted ray will not be a straight line, but a curve. This will be understood better by referring to fig. 2, Plate 1. Until the ray of light enters the atmosphere its course is a straight line. Henceforward, however, it is bent more and more as it passes through each successive stratum of air; and the result is, that its course through the atmosphere assumes the form of a curve, which is concave towards the earth's surface. In the figure referred to, the reader will perceive a tangent drawn to the course of the ray at the point where it reaches the earth's surface. This represents the direction in which the celestial object is seen by an observer at the earth's surface, and is manifestly different from the line joining the object and the same point, which indicates the true direction of the object relatively to the observer. The effect, then, of refraction, is obviously to elevate a celestial object apparently above its true place.

The refraction of a celestial object gradually diminishes from the horizon, where it is greatest, to the zenith, where it vanishes altogether. For objects situate in the horizon, the refraction amounts to rather more than 34′; at 5° of altitude above the horizon, its mean value is 10′; at 20°, it is 2′ 30″; at 45°, it is 57″—and so on, as illustrated in fig. 2, Plate 1.

The refraction of a celestial object does not depend solely on the altitude of the object above the horizon. It is also to a certain extent affected by the temperature and pressure of the atmosphere, and by the quantity of aqueous vapour contained therein; and as these elements are continually fluctuating within small limits, the amount of refraction is also incessantly undergoing corresponding small variations.

There is always some degree of uncertainty with respect to the refraction of celestial objects, the apparent positions of which are very near the horizon. This arises from our not being sufficiently acquainted with the physical changes which are perpetually occurring in the lower regions of the atmosphere, and which especially affect the refraction of rays traversing horizontally the lower strata of air. It is consequently the practice of astronomers to confine their observations to objects the apparent positions of which are elevated to some extent above the horizon.

It is owing to refraction that we see the sun and moon on the horizon, when they are in reality depressed beneath it. In point of fact, the sun is visible in the morning about four minutes *before* it has ascended above the horizon, and is visible in the evening about four minutes *after* it has descended beneath it. The explanation of this is very simple. The refraction at the horizon amounts to at least 33′, or rather more than the apparent diameter of either the sun or moon. Hence those bodies may be wholly visible above the horizon, from the effect of refraction, when they are in reality depressed beneath it; and as they occupy about four minutes in ascending above the horizon, and the same time in sinking beneath it, the duration of sunlight or moonlight is manifestly prolonged by refraction to the extent of about eight minutes.

Another remarkable phenomenon explicable by refraction is this: when the sun or moon is upon the horizon, the disc exhibits an oval shape, the vertical diameter being sensibly smaller

than the horizontal diameter. This arises from the unequal effect of refraction upon the upper and lower extremities of the vertical diameter, combined with the fact of the horizontal diameter being altogether unaffected by the same cause. Let us consider the case of the sun. The mean value of the sun's apparent diameter may be said to amount to 32′. Again, the variation of refraction at the horizon amounts to about 4′ for an elevation above the horizon to the extent of 32′. Hence it is clear that when the sun is upon the horizon the effect of refraction upon the lower extremity of the vertical diameter will exceed the effect upon the upper extremity to the extent of 4′, and the result consequently is, that the vertical diameter will be reduced from 32′ to 28′. On the other hand, the horizontal diameter being wholly unaffected by refraction, will retain its normal value of 32′. Hence originates the oval shape exhibited by the sun's disc when it is on the horizon. The same explanation is obviously applicable to the case of the moon.

Aberration.—The principle of the aberration of light may be thus illustrated: Suppose a shower of rain is falling in heavy drops during a dead calm. To a person standing still the drops will be seen descending in their true direction, which is perpendicular to the horizon. Let us, however, suppose the person to walk forward. In this case the drops will meet his face, and the direction in which they seem to descend will no longer be strictly vertical, but somewhat inclined to that direction, as represented in fig. 4, Plate I. This apparent displacement of the falling direction of the drops of rain is an accurate illustration of the aberration of light.

Another illustration, due to Mr Airy, the Astronomer-Royal, is this: Let us suppose a shot to be fired from a land-battery upon a vessel sailing quickly on the sea or on a river, and to pass through the sides of the vessel. A comparison of the place where the shot entered the vessel with the place where it quitted the vessel on the opposite side will not represent the true direction of the shot, but will rather indicate it as having come from a quarter *somewhat ahead*, the amount of displacement depending on the relative velocities of the shot and the vessel. If we suppose in this case the shot to represent a ray of light, and the vessel to represent the earth travelling in its annual orbit round the sun, the displacement referred to will constitute an exact representation of the apparent displacement produced in the position of a celestial object by the aberration of light (see fig. 5, Plate I).

The aberration of a celestial object for any assigned instant of time depends on the corresponding position of the earth in its orbit; it is therefore perpetually varying throughout the year. Its general effect is to cause every star to describe apparently a small ellipse in the heavens round its true place. The major axis of this ellipse is invariable; it amounts to 40″.8. The magnitude of the minor axis, on the other hand, depends on the angular distance of the star from the ecliptic. It is greatest for a star situate in the pole of the ecliptic, where it is equal to the major axis, and where, consequently, the ellipse becomes a circle. From this point it gradually diminishes towards the ecliptic, where it finally vanishes altogether, and the ellipse of aberration becomes a straight line, whose length is equal to the major axis of the ellipse, or, in other words, equal to 40″.8.

Precession.—This consists in a slow motion of the equinoctial points of the celestial sphere in a direction opposite to the apparent motion of the sun and planets. The result is a uniform increase in the longitudes of the heavenly bodies when observed from year to year, the latitudes remaining unchanged. The precession in longitude amounts to 50″.1 annually, and is the same for all the celestial bodies. If the place of an object be represented by its right ascension and declination, the effect of precession will be to cause a slow but continual variation of both these elements, the amount in either case depending on the position of the object in the celestial sphere.

The annual motion of the equinoctial points of the celestial sphere producing the phenomenon of precession is in reality due to a terrestrial movement, being the result of an excessively slow conical motion of the earth's axis round the pole of the ecliptic in a direction opposite to that of the diurnal motion of the same body. The time occupied by the earth's axis in effecting a complete revolution round the pole of the ecliptic is 25,868 years.

Nutation.—This may be regarded as a modification of precession. If there was no nutation the effect of precession would be to make the pole of the celestial equator describe with a uniform motion a circle round the pole of the ecliptic. In virtue of nutation, the pole of the celestial equator does not proceed uniformly in this circle, but is made to describe a small ellipse in the heavens round the place which it would otherwise occupy if it were influenced solely by precession. The time which it occupies in effecting a complete revolution in this ellipse is eighteen years and ten days. The major axis of this small ellipse is 18".25; the minor axis is 13".7.

Parallax.—In its more general sense, parallax is the change of direction which an object undergoes when observed from two different stations. As understood in the present chapter, it has a more confined application, being intended merely to represent the change of direction which a celestial object undergoes when viewed from the centre of the earth, and from some point on its surface. It is greatest when the object is in the horizon, and diminishes thence towards the zenith, where it vanishes altogether. This will be evident by reference to fig. 3, Plate 1. Let the object be in the horizon at B, the angle O B A representing the difference of direction of two lines, one drawn to the observer and the other to the centre of the earth; in other words, the parallax of the object will then be the greatest possible. The angle O B A is usually termed the horizontal parallax of the object. The nearer an object is to the earth the greater will be its parallax. This will be also obvious by inspection of fig. 3. Generally speaking, the horizontal parallax of a celestial object is a very small quantity, except in the single case of the moon, the parallax of which may, when it is in some parts of its orbit, even exceed a degree. The parallax of Saturn, which is distant from the earth nearly nine hundred millions of miles, amounts only to about 1". In the case of Uranus or Neptune it is manifestly still smaller. The parallax of the fixed stars is altogether insensible.

In the explanation of parallax just given, we have considered it merely as the correction which must be applied to the observed position of a celestial object in reducing it from the actual place of observation to the centre of the earth. It is called the *diurnal* parallax, in contradistinction to the *annual* parallax, which results from the motion of the earth in its orbit, and to which we shall hereafter refer.

CHAPTER VI.

Illustrations of the Phenomena of Day and Night—The Vicissitudes of the Seasons Explained.

The grand phenomenon of the diurnal motion of the heavens from east to west in twenty-four hours, and the vicissitudes of the seasons on the earth's surface, admit of a satisfactory explanation by the revolution of the earth on a fixed axis in the opposite direction, and its annual revolution round the sun, also in the opposite direction, or from west to east.

Since the sun can illuminate only a half of the earth's surface at one time, it follows as a necessary consequence that while it is day on any hemisphere of the earth it is night on the opposite hemisphere. To an observer in the one hemisphere the sun will be seen above the horizon, to an observer in the opposite hemisphere the nocturnal phenomena of the stellar heavens will be visible. The bounding-line between day and night will obviously be travelling perpetually on the earth's surface, accomplishing a complete revolution in twenty-four hours. An illustration of the phenomena of day and night is given in fig. 1, Plate 2. The south pole is illuminated by the sun's rays; the north pole is involved in darkness. The sun is high above the horizon relatively to Eastern Africa; it is similarly depressed beneath the horizon relatively to the central regions of the American continent.

In order to understand clearly how the vicissitudes of the seasons arise from the orbital motion of the earth around the sun, it will be desirable to consider some of the leading features of the sun's apparent annual motion in the heavens.

It has been already stated that the apparent path of the sun is a great circle of the sphere, which consequently cuts the celestial equator in two opposite points. These points are termed the equinoxes, because when the sun is passing through either of them, day and night are equal all over the world. The equinox in which the sun is situate when it is passing from the south to the north of the equator is termed the vernal equinox; the other is termed the autumnal equinox. After the sun has passed through the vernal equinox, its northern declination increases daily, and as a necessary consequence the day becomes gradually longer and the night shorter everywhere in the northern hemisphere, while the day becomes correspondingly shorter and the night longer everywhere in the southern hemisphere. On the 21st of June the sun's northern declination has attained its maximum value of 23° 27′. The day is now longest and the night shortest in the northern hemisphere, while the day is shortest and the night longest in the southern hemisphere. The sun is said to be at this time in the summer solstice. Henceforward the sun's north declination diminishes daily, consequently the days shorten and the nights lengthen in the northern hemisphere; while again in the southern hemisphere the converse of this exactly occurs. On the 21st of September the sun is again in the equator, and day and night are once more equal over the whole world. The sun now passes to the south of the equator, the declination increasing daily, and attaining its maximum value of 23° 27′ on the 21st of December, when the sun is said to be in the winter solstice. The days are now shortest and the nights longest everywhere in the northern hemisphere, while the days are longest and nights shortest everywhere in the southern hemisphere. From the winter solstice the sun advances in its eastward course, now however returning north towards the equator, which it finally reaches on the 21st of March, and thus completes the cycle of its annual movement.

When the sun is passing through either of the equinoxes, it will be vertical relatively to the terrestrial equator. Further, if we suppose two small circles to be drawn on the earth's surface parallel to the equator, one on the north side of it at a distance equal to 23° 27′, the other on the south side, at a distance also equal to 23° 27′, the sun throughout the year will necessarily be vertical somewhere in the region comprised between those two circles. The northern parallel is termed the *tropic of Cancer*, the southern is termed the *tropic of Capricorn*. These two circles obviously correspond to the celestial circles of the same designation.

The explanation of the seasons by the earth's annual motion round the sun is illustrated in fig. 2, Plate 2. The inner ellipse represents the annual path of the earth round the sun. On the outer ellipse are laid down the months of the year, corresponding to the earth's orbital motion. While the earth travels round the sun, its axis remains constantly parallel to itself, being inclined to the plane of the orbit at an angle of about 23° 27′. The position of the earth

on the 21st of March is represented in the lower part of the figure. It corresponds to the time of the vernal equinox. The north and south poles are then similarly situated with respect to the sun, and the result is that day and night are equal all over the world.

As the earth travels in its orbit, the north pole is gradually turned more and more towards the sun, while the south pole is similarly turned away from it. The result is, that everywhere in the northern hemisphere the day is longer than the night, while in the southern hemisphere the night is longer than the day. This process continues until the 21st of June, when the north pole is turned as much as possible towards the sun, and the south pole is similarly turned away as much as possible from it. In other words, it is the time of the summer solstice. The day is now longest and the night shortest everywhere in the northern hemisphere, while the day is shortest and the night longest everywhere in the southern hemisphere.

As the earth revolves round the sun, the north pole gradually turns away from the latter body, while the south pole turns towards it, until, on the 21st of September, both poles are turned similarly towards the sun, and day and night are again equal all over the world. It is now the time of the autumnal equinox.

Henceforward the north pole continues to turn away from the sun, while the south pole turns towards it, and the night is now longer than the day in the northern hemisphere, and the day longer than the night in the southern hemisphere. On the 21st of December the north pole is turned away as much as possible from the sun, while the south pole is turned as much as possible towards it, and the result is that everywhere in the northern hemisphere the day is shortest and the night longest, while in the southern hemisphere the day is longest and the night shortest. It is now the time of the winter solstice.

As the earth continues to travel in its orbit the north pole begins again to turn towards the sun, and the day becomes longer and the night shorter in the northern hemisphere, while the day becomes shorter and the night longer in the southern hemisphere. At length, on the 21st of March, the north and south poles are again similarly situated with respect to the sun, and day and night are again equal all over the world.

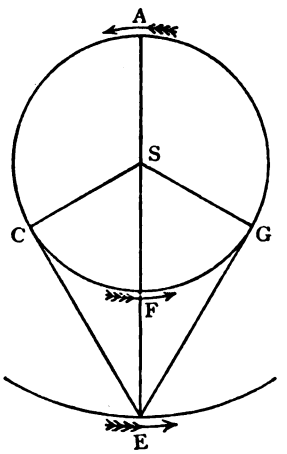
It is obvious from the foregoing explanation that at the time of the summer solstice a region of definite extent around the north pole is involved in perpetual day, and that a region of equal extent around the south pole is involved in perpetual night. It is equally apparent that at the time of the winter solstice the converse of this holds good, the region around the north pole being involved in perpetual night, and the region around the south pole being involved in perpetual day. If a small circle parallel to the equator be described at a distance of $23^\circ\ 27'$ from the north pole, it will form the boundary of the region of perpetual day or perpetual night around the north pole; and if a similar small circle be described at an equal distance from the south pole, it will constitute the boundary of the corresponding region around the south pole. The former of these circles is termed *the Arctic Circle*, the latter is termed *the Antarctic Circle.*

CHAPTER VII.

Apparent Movements of the Planets—Inferior Planets—Superior Planets.

A view of the planetary system is exhibited in Plate 7. The sun occupies the centre, while the planets, accompanied by their respective satellites, revolve in orbits of various magnitudes around it. The apparent movements of the planets are affected by the motion of the earth round the sun. This circumstance has suggested their division into two distinct classes—namely, inferior planets, or those which revolve within the earth's orbit; and superior planets, or those which revolve beyond the earth's orbit. The inferior planets are Mercury and Venus. The superior planets are Mars, the minor planets, Jupiter, Saturn, Uranus, and Neptune. Plate 8 contains an enlarged view of the position which the earth occupies in the solar system.

The inferior planets are distinguishable from the superior planets by the circumstance that they never deviate beyond a certain angular distance from the sun. Sometimes they are seen a little to the east of the sun; at other times they appear to the west of that body. In the former case they are visible in the heavens shortly after sunset; in the latter, they appear in the morning before sunrise. Another interesting feature of the inferior planets



consists in their exhibiting phases like the moon. This will be readily understood by aid of the annexed figure. Let A C F G represent the orbit of the inferior planet, S the sun, and E the earth. For the sake of illustration, we shall assume the earth to be at rest while the planet performs a complete revolution round the sun, and that both earth and planet revolve in the same plane.

When the planet is at A in the prolongation of the line joining the earth and sun, the illuminated half of its surface is turned wholly towards the earth, and it will present the appearance of the full moon. When it is at F, which is situate in the line joining the earth and sun, the unenlightened hemisphere is turned wholly towards the earth, and like the new moon it is invisible. When it has revolved from A to C, a point so situated that the line C S drawn between it and the sun is perpendicular to C E, the line drawn between it and the earth, the half of the illuminated surface is turned towards the earth, and the other half is turned away from it. In this case the planet will resemble in appearance the half moon. It is obvious

that in any position between A and C the planet will appear gibbous, while between C and F it will resemble a crescent. The same succession of phases, but in a reverse order, will be exhibited as the planet revolves from F to A. An illustration of the phases of an inferior planet is given in fig. 7, Plate I.

The line E F S A, passing through the earth, the sun, and the planet, is termed the line of conjunction. The planet is said to be in *superior conjunction* when it is at A, and to be in *inferior conjunction* when it is at F.

Let us now consider the variable position of the planet relatively to the sun, as viewed from the earth. When the planet is at A, or in superior conjunction, it appears in the same direction as the sun. It will therefore rise and set simultaneously with the sun. As the planet revolves from A, it deviates more and more to the *east* of the sun, and the result is that after sunset it begins to be visible in the western sky. The angular deviation of the planet from the sun is technically termed the *elongation* of the planet. The angle of elongation attains its maximum value when the planet is at C, where a tangent to the orbit passes through the earth.* Henceforward the planet apparently approaches the sun until, upon its arrival in inferior conjunction at F, it would again, *if it were visible*, appear in the same direction as the sun, and both bodies would rise and set simultaneously. As the planet revolves from this position it deviates to the *west* of the sun, and it now begins to appear in the morning shortly before sunrise. This goes on increasingly until the arrival of the planet in G, when its western elongation is the greatest possible. Henceforward it approaches the sun, and finally appears again in the same direction with that body upon its arrival in A, or rather *would* appear if it were visible in such a position, and not lost, as it really is, in the sun's rays.

It is clear, from the foregoing explanation, that when the planet is to the east of the line of conjunction it is visible in the western sky after sunset, and that when it is to the west of the line of conjunction it appears in the eastern sky before sunrise.

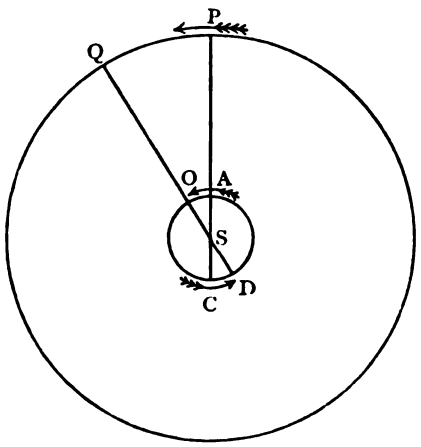
The maximum elongation, whether eastern or western, will be greater for Venus than for Mercury, because it revolves at a greater distance from the sun. But even for the same planet the greatest elongation will be different at different times in consequence of the excentricity of its orbit; for although, for the sake of illustration, we have supposed the orbits of both planets to be circular, they are in reality elliptical, considerably so in the case of Mercury. The greatest elongation of Venus varies between 45° and 48°; the greatest elongation of Mercury varies between 16° and 29°.

We have assumed in the foregoing explanation that while the planet revolves round the sun the earth remains at rest. If, however, we took into account the earth's motion, the general effect would be the same: the only difference would be, that the planet would take a longer time to complete the cycle of its positions relatively to the sun and the earth. Hence, also, any critical positions, such as the points of greatest elongation and of inferior conjunction, will not coincide with the positions laid down in the figure, but will be further advanced on the orbit; nor will the return of the planet to superior conjunction occur at A, but at a point farther advanced, depending on the relative motions of the earth and the planet. The interval between two consecutive returns of the planet to the same position relatively to the earth and the sun is termed a *synodic revolution*. It is easy to see that the synodic revolution of an inferior planet generally surpasses in duration the sidereal revolution. Thus, in the case of Venus, while the sidereal revolution does not exceed 224 days in round numbers, the synodical revolution amounts to 584 days.

* The orbit of the planet is here supposed to be circular.

Another interesting feature of the apparent movements of the inferior planets consists in this, that they travel sometimes with a direct motion, and other times with a retrograde motion. Thus, when the planet is at A and the earth at E, they are travelling in opposite directions; and an observer on the earth's surface, being unconscious of his own motion, transfers it in the opposite direction to the planet. The result is, that the planet in this position appears to travel rapidly in the direction of its real motion. Again, when the planet is at F, it is travelling in the same direction as the earth; but being nearer to the sun, its velocity is greater than that of the earth, and consequently the observer, who transfers his own motion to the planet in the contrary direction, perceives the planet travelling with an angular motion, measured by the excess of its own orbital velocity, over that of the earth, in a direction contrary to that in which it was travelling when at A. In this case, then, the motion of the planet is retrograde, or contrary in direction to the usual motion of the planet. The motion of the planet being direct at A, and retrograde at F, it is obvious that, in certain intermediate positions between A and F, and between F and A, the planet must be neither direct nor retrograde; in other words, it must be stationary. All this is exactly conformable to what observation indicates in regard to the apparent motion of the planet.

One or two remarks on the superior planets will be sufficient. We have seen that the inferior planets never deviate beyond a certain angular distance from the sun. The superior planets, on the other hand, are seen at all distances from the sun, even in the opposite region



of the heavens. Thus, let the interior of the two orbits in the annexed figure represent the earth's orbit, and let the exterior represent the orbit of the superior planet. Let S denote the sun, and draw the line P A S C. When the planet is at P and the earth at A, the direction of the planet will be diametrically opposite to that of the sun. The planet is then said to be in *opposition*. On the other hand, when the planet is at P and the earth at C, the sun and the planet will appear in the same direction of the heavens relatively to the earth. In this case the planet is said to be in *conjunction*. The line joining the planet, the earth, and the sun in either case is called the line of conjunction. It is plain that when the planet is in opposition it is nearest the earth, and when it is in conjunction it is most remote from that body, the difference of distance in these two extreme cases amounting to a diameter of the earth's orbit.

As in the case of the inferior planets, the apparent movement of a superior planet is sometimes direct and other times retrograde. Thus, let us suppose the planet to be in opposition, in

which case the place of the planet being represented by P, that of the earth will be represented by A. The earth and planet are now travelling in the same direction, but the earth, being the nearer of the two bodies to the sun, travels with greater speed, and leaves the planet behind; and the result is that, to an observer on the earth who is unconscious of his own motion, the planet appears to be travelling with a motion contrary in direction to that by which it is usually characterised. It appears, then, that when a planet is in opposition its motion is retrograde. Let us now suppose the planet to be in conjunction, in which case, assuming the planet to be at P, the place of the earth will be represented by C. The earth and planet are now travelling in opposite directions, and the result is that the motion of the planet will be rapidly direct.

The motion of a superior planet being thus direct in conjunction and retrograde in opposition, there are manifestly two intermediate positions in which it may be regarded as stationary.

The same distinction which exists between the sidereal and synodic revolutions of an inferior planet holds good also in the case of a superior planet. Let us suppose the planet to be in opposition at P. If the planet remained at rest while the earth revolved round the sun, it would again be in opposition when the earth had returned to A. But this supposition is not consonant to fact. While the earth is revolving in its orbit the planet also is revolving, although with a slower motion, in the same direction. The result is, that when the earth, after accomplishing a revolution round the sun, has returned to A, the planet has already quitted P, and it will not be again in opposition until the earth has revolved through the additional arc A O, when the planet at Q is again in the same straight line with the earth and sun.

The time of a synodic revolution of a superior planet is measured by the interval included between two successive returns of the planet to the same position relatively to the earth and the sun. It is manifest that the circumstances relating to the direct and retrograde movements of the planet complete the cycle of their changes only in the time of a synodic revolution.

We have supposed, for simplicity of explanation, that the planets all revolve in the plane of the earth's orbit. This, however, is not strictly true. The plane of the orbit of every planet is inclined at a greater or less angle to the plane of the orbit in which the earth revolves—in other words, to the plane of the ecliptic. As regards the eight principal planets, the inclination of the orbit to the ecliptic is in every instance inconsiderable. In the case of Mercury, which offers the greatest deviation in this respect, the inclination of the orbit does not exceed 7°. The minor planets, on the other hand, deviate from the plane of the ecliptic to a much greater extent.

Plate 21 contains an illustration of the apparent paths of Venus, Mars, Jupiter, and Saturn for periods comprised within the years 1868-69.

CHAPTER VIII.

Real Movements of the Planets—Kepler's Laws—Elements of the Eight principal Planets.

In the last Chapter we have shown that the phenomenon of the retrograde movements of the planets arises, in each instance, from the observer unconsciously confounding his own motion round the sun with the motion of the planet. But, independently of this circumstance, there exist in the apparent motion of every planet irregularities which clearly prove that

the real motion is not uniform. When the effects of the earth's motion have been eliminated, and the motion of the planet has been referred to its true centre the sun, it is found that the velocity of the planet is invariably greatest when it arrives in a certain region of the heavens, and is least when it is in the region directly opposite, and that between those two positions the velocity gradually diminishes from its greatest to its least value. Further, it is found that the distance* of the planet from the sun is continually varying, being *greatest* when the velocity is *least*, and *vice versâ*. It is clear from this last circumstance that the orbit of the planet is not circular. The Greek astronomers did not fail to discover this important fact, and they endeavoured to represent the orbit of each planet by a combination of circles. It was reserved for the immortal Kepler to demonstrate that the orbit of every planet is essentially an oval, which no combination of circles can rigorously satisfy. The discoveries of this great astronomer relative to the orbits of the planets and the laws of their movements are embodied in three famous theorems, which have been designated by the appellation of Kepler's Laws. They are expressed in the following terms :—

1. The orbit of each planet is an ellipse, of which the sun occupies one of the *foci*.

2. If an imaginary straight line be drawn connecting the planet with the sun, it will sweep over equal areas in equal times.

3. The squares of the times of revolution of the planets are proportional to the cubes of their mean distances from the sun.

The first of these theorems defines the form of the curve in which the planet revolves, and its position with respect to the sun. The second expresses the law which regulates the velocity of the planet in its orbit. The third determines the relation which exists between the mean distances of the planets and their times of revolution round the sun.

It has been established by the researches of astronomers that the movements of comets round the sun, and the movements of the satellites round their respective primaries, are also in every instance regulated in accordance with Kepler's laws.

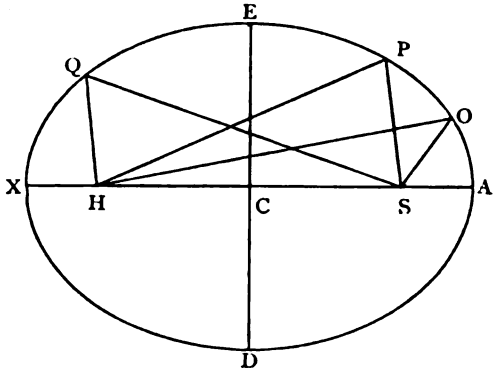
Newton demonstrated that the three laws of Kepler are necessary consequences resulting from the attractive force which the sun exercises perpetually upon the planets, combined with the supposition of an original impulsive force directed in each instance along a tangent to the orbit.

The ellipse is an oval curve having two points in the interior, termed the foci, so related to it that if from any point in its contour two straight lines be drawn, one to each focus, the sum of such lines is always the same. Thus, in the annexed figure, which represents an ellipse of which S and H are the foci, if we take any number of points, O, P, Q, in the curve, and if we draw the lines O S, O H, P S, P H, Q S, Q H, then will the three pairs of lines thus drawn be all exactly equal to each other; namely, O S added to O H will be equal to P S added to P H, and each of these aggregates will be equal to Q S added to Q H. This is the fundamental property of the ellipse.

If a straight line be drawn connecting the two foci, S and H, and if it be extended both ways so as to meet the ellipse in the points A and X, and if E D be drawn at right angles to A X, bisecting it in C and meeting the ellipse in the points E and D, then is C the centre of the ellipse, A X the major axis or longest diameter, and E D the minor axis or shortest diameter. Furthermore, the fraction represented by the proportion of C S to C A the semi-minor axis, is termed *the excentricity* of the ellipse. The reason of this designation is obvious. Thus, the farther S and H diverge from C, and consequently the nearer they approach to A and X, the greater will be the excentricity of the ellipse,—in other words, the more will the

* The distance from the sun is here understood to be, not the absolute distance (with which the ancients were totally unacquainted), but the *relative* distance.

ellipse deviate from a circle. On the other hand, the more closely S and H approach to C (the length of A X, the major axis of the ellipse, being supposed in this as in the preceding case to be always the same), the smaller will be the excentricity, and the more nearly will the ellipse coincide with a circle whose diameter is A X.



If we now suppose a planet to revolve in the ellipse A E X D, it follows as a necessary consequence of Kepler's first law that the sun will be situated either in S or H, one or other of the two foci of the orbit. Let us suppose it to be situated in the focus S. Then the planet will be nearest the sun when it is at A, and it will be most remote from that body when it is at X, the opposite extremity of the major axis. The point A is termed *the perihelion*, which is derived from two Greek words signifying *near the sun*. The point X is termed *the aphelion*, which is similarly derived from two Greek words signifying *away from the sun*. In like manner A S is termed *the perihelion distance*, and X S *the aphelion distance*. The average of all the distances of the planet from the sun embraced in a complete revolution of the planet is termed *the mean distance*. The orbit of a planet, as already stated, does not in any case coincide with the plane of the earth's orbit, being generally inclined to it at a certain definite angle, which is different for each planet. Since the plane of the planet's orbit passes through the sun, it necessarily intersects the earth's orbit, or in other words, the ecliptic in two opposite points termed *the nodes*. When the planet is in either of the nodes it is then manifestly also in the plane of the ecliptic. In every other position it is situated either to the north or the south of the ecliptic. The node in which the planet is situated, when it is passing from the south to the north of the ecliptic, is termed *the ascending node;* the opposite node of the orbit, or that in which the planet is situated when it is passing from the north to the south of the ecliptic, is termed *the descending node*.

The elements of the orbit of a planet are six in number, namely :—

1. The mean distance from the sun.
2. The excentricity of the orbit.
3. The longitude of the perihelion.
4. The inclination of the orbit to the ecliptic.
5. The longitude of the ascending node.
6. The mean longitude of the planet, corresponding to a given epoch.

The first and second of these elements define the magnitude and form of the orbit. The third fixes the position of the orbit in its plane. The fourth and fifth define the position of the plane of the orbit with respect to the ecliptic. The sixth enables us to assign the mean place of the planet in its orbit corresponding to any given epoch. These six elements being

ascertained from observation, we may then, by means of Kepler's laws, compute the place of the planet in its orbit for any assigned time, whether past or future.

The elements of the orbit of a planet are varying from year to year, although with excessive slowness, in consequence of the disturbing action of the other planets of the system. Moreover, the starting-point of the longitudes, or first point of Aries, is continually varying, from the precession of the equinoxes. It is necessary, therefore, in giving the elements of a planet, to assign also the epoch to which the results refer. The following are the elements of the eight principal planets, the epoch being 1850, January 1, Paris mean time. Besides the six fundamental elements, there is also given the sidereal revolution, which is not an independent element, being directly derivable from the mean distance by means of Kepler's third law.

ELEMENTS OF THE ORBITS OF THE EIGHT PRINCIPAL PLANETS FOR THE MIDDLE OF THE NINETEENTH CENTURY.

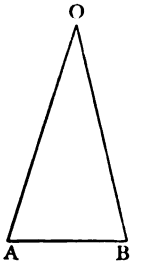
Name of Planet.	Mean Distance from the Sun.	Sidereal Revolution in Days.	Excentricity.	Longitude of the Perihelion.	Inclination of the Orbit to the Ecliptic.	Longitude of the ascending Node.	Mean Longitude.
Mercury, .	0.38710	87.97	0.20562	75° 7′ 0″	7° 0′ 8″	46° 33′ 3″	327° 15′ 20″
Venus, .	0.72333	224.70	0.00683	129 23 56	3 23 31	75 19 4	245 33 14
The Earth, .	1.00000	365.26	0.01677	100 21 40	...	...	100 46 36
Mars, . .	1.52369	686.98	0.09326	333 17 51	1 51 5	48 22 45	83 40 51
Jupiter, .	5.20280	4332.58	0.04824	11 54 53	1 18 40	98 54 20	160 1 20
Saturn, .	9.53885	10759.22	0.05599	90 6 12	2 29 28	112 21 44	14 50 41
Uranus, .	19.18264	30686.82	0.04658	168 16 45	0 46 30	73 14 14	28 26 41
Neptune, .	30.03700	60126.72	0.00872	47 14 37	1 46 59	130 6 52	335 8 58

Some details respecting the minor planets will be given hereafter.

CHAPTER IX.

Explanation of the Method for Determining the Distance of an Inaccessible Object—Determination of the Distances of the Celestial Bodies—Sun's Horizontal Parallax.

The method employed by astronomers in determining the distances of the heavenly bodies from the earth is founded upon exactly the same principle as that which is used for a similar



purpose in ordinary surveying operations. For instance, let O be an inaccessible object on the earth's surface, as a tree or a tower, and A a station from which it is visible, and let it be supposed that we wish to know the distance of the object from A. To this end we select another station, B, in the vicinity of A, and carefully measure with a rod or chain the distance in feet

between the two stations. We then measure with a theodolite or sextant the angles O A B, O B A, which the object subtends with B when viewed from A, and with A when viewed from B. Now it is a fundamental property of trigonometry that when three parts of a triangle (of which one is necessarily a side) are known, the remaining parts may be deduced from them by a process of pure computation. But in the triangle O A B the base A B is known, and also the angles A and B, which are at the base. Hence we are enabled to compute the remaining parts of the triangle, and thus we ascertain the value of O A, which represents the distance of the object from the original station A.

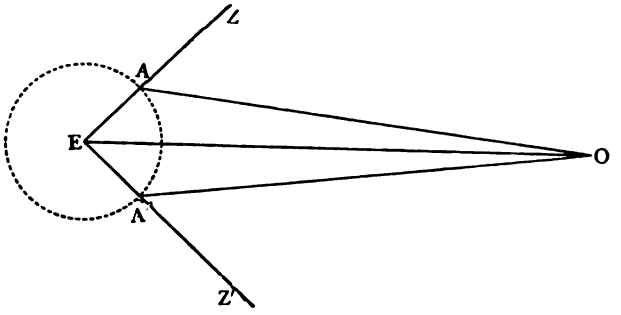
Since in all cases the three angles of a triangle are together equal to two right angles, and since the angles A, B, at the base of the triangle O A B are known by measurement, it necessarily follows that the angle O at the vertex of the triangle is hence directly ascertained. This angle obviously measures the change of direction which the object undergoes when the observer shifts his station from A to B. It is consequently termed *the parallax* of the object. This agrees essentially with the explanation of parallax given in Chapter V. In that case, however, it was considered merely as the correction to be applied to the apparent position of a celestial body observed anywhere on the earth's surface, in order to reduce it to the position which it would occupy if observed from the centre of the earth. In the present instance, parallax is viewed as an element for ascertaining the distance of an inaccessible object, whether celestial or terrestrial.

The more distant the object O is relatively to A and B, the more nearly the lines O A, O B, will approach to parallelism, and consequently the smaller is the change of direction which the object will undergo when the observer shifts his position from A to B; in other words, the smaller will be the parallax of the object. Hence it is easy to understand that the distance of O may be so remote relatively to A or B that the instrument of the observer may fail to indicate any sensible change of direction as the observer passes from A to B. It is true that this difficulty might be obviated by an extension of the base A B, for the effect of such an extension would manifestly be to produce a greater change of direction, or, in other words, to lead to an enlargement of the angle of parallax. But if the base is of limited extent, there exists no remedy from this source.

Parallax of a Celestial Object.—We are thus led to consider the difficulty which offers itself in endeavouring to determine the distance of a celestial body from the earth. This difficulty arises from the excessive remoteness of the object relatively to the extent of the base from which the observations of its apparent position are made. The earth is a body of limited magnitude, its diameter measuring in round numbers eight thousand miles. Now it was universally found by astronomers down till towards the close of the seventeenth century, that if the apparent position of a celestial body was observed at any two stations on the earth's surface, however remote from each other, the change of direction, or, in other words, the parallax, was insensible except in the single case of the moon. It is the triumph of modern astronomy to have surmounted this difficulty.

It has been already stated (Chapter V.) that the parallax of a celestial object is measured by the difference of direction which it would exhibit if observed from the centre of the earth and anywhere on its surface, and that the parallax so defined attains its maximum value when the object is upon the horizon of the observer. Let O be a celestial object observed from two distant stations, A, A′, supposed to be on the same meridian, and on opposite sides of the equator. Let E represent the centre of the earth, and E A Z, E A′ Z′ the directions of the zenith at A and A′ respectively. The angle Z A O represents the zenith distance of the object as seen at A, or the complement of the altitude. Similarly the angle Z′ A′ O represents the zenith distance of the object at A′. In like manner the angle A O E represents the parallax

of the object at A, and the angle A′ O E the parallax at A′. By a well-known property of triangles, the zenith distance Z A O exceeds the angle A E O by the parallactic angle A O E, and similarly the zenith distance Z′ A′ O exceeds the angle A′ E O by the parallactic angle



A′ O E. Hence the sum of the zenith distances at A and A′ exceeds the angle A E A′ by the angle A O A′, representing the sum of the parallaxes at A and A′. But the angle A E A′ represents the sum of the latitudes at A and A′, and is therefore known; again, the zenith distances at A and A′ are known by observation; hence the angle A O A′ is also known. Hence, finally, the ratio of A E to E O, which measures the sine of the horizontal parallax of the object, may be found by a simple process of computation.

Problem of the Solar Parallax.—In the case of the moon, the magnitude of the angle A O A′ is so considerable that the value of the horizontal parallax is easily ascertained. It is quite different, however, when the question refers to the sun or any of the planets. With respect to the sun, the determination of the parallax by a direct process is impracticable, partly in consequence of the smallness of that element, partly from the difficulty of the observation, and partly from the uncertainty which exists respecting the precise amount of influence exercised by refraction on the apparent position of the sun. It is quite clear, however, that if we once determined the value of the solar parallax, or, which amounts to the same thing, the distance of the earth from the sun, we should then be in a position to determine the absolute distances of all the other planets from the sun—for the *relative* distances of the planets from the sun have long been ascertained with great precision; and consequently, when the absolute distance of any one of them is known, the absolute distances of all the others may be computed by a process of simple proportion.

Mode of Attack.—But although astronomers have been unable to determine the value of the solar parallax by a direct process, it has been found practicable to effect the object in another way. It is plain that if the parallax of any one of the planets was ascertained by direct observation, we should then, knowing the relative distances of the earth and the planet from the sun, be enabled to deduce the value of the solar parallax. Now there are two planets which, in the course of their revolution round the sun, approach comparatively near to the earth. These are the neighbouring planets, Venus and Mars, which revolve, the one immediately within the earth's orbit, the other immediately beyond it. If we suppose the distance of the sun from the earth to be represented by 100, the distance of Mars from the earth sometimes descends to 37, while the distance of Venus when nearest the earth does not exceed 28. It is evident, therefore, that under certain circumstances the parallax of either of those planets considerably exceeds the sun's parallax. Accordingly, astronomers have obtained two important solutions of the problem of the solar parallax by methods founded respectively upon observations of Venus and Mars.

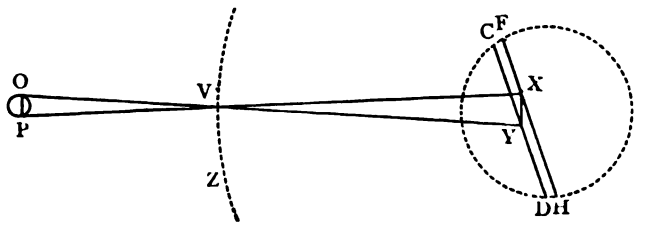
Solution of the Problem by Observations of Mars.—The solar parallax has been deter-

mined from simultaneous observations of the planet Mars made at stations in the northern and southern hemisphere, in accordance with the method which has just been explained. From observations of the planet made at Greenwich and Williamstown, Victoria, in the year 1862, Mr Stone, First Assistant at the Royal Observatory, Greenwich, found the solar parallax to be 8".943. M. Winnecke, a German astronomer, by a similar discussion of observations of the planet, made in the same year at the Imperial Observatory of Pulkowa in Russia, and Santiago in Chili, obtained 8".964 as the value of the solar parallax. The mean of these results gives 8".953 as the definitive value of the element heretofore deducible from observations of the planet Mars.

We have supposed in the foregoing explanation that the two stations from which the planet is observed are situated on the same meridian. It is not necessary, however, that this condition should be strictly fulfilled. It is sufficient that the two stations should be *nearly* on the same meridian, for in that case the observations of the planet at one of the stations, combined with the theory of its motion, enable us to ascertain the exact zenith distance which it would attain when it passed the meridian of the other station. In this way we obtain two simultaneous zenith distances, which are at once comparable with each other.

Its Solution by Observations of the Transit of Venus over the Sun.—The planet Venus, when in inferior conjunction, approaches still nearer to the earth than Mars does, even under the most favourable circumstances. It is, however, unsuitable for the determination of the solar parallax by the method which has been employed in the case of Mars, for two reasons. In the first place, when the planet is in inferior conjunction it is in the immediate vicinity of the sun, and is from this cause necessarily invisible. But independently of this circumstance, the planet cannot be *generally* seen at the time of inferior conjunction, because the unenlightened half of its surface is then turned wholly towards the earth. There are, however, certain rare occasions when the planet passes directly between the sun and the earth, and when it consequently exhibits the appearance of a round black spot traversing the solar disc. Observations of such phenomena (technically termed *transits* of the planet) have suggested the best method which has yet been devised for determining the value of the solar parallax. A general idea of the method may be derived from the following illustration.

Let O P be two positions on the earth's surface, the one near the north pole, the other near the south pole. Let us suppose now that when the planet Venus is in inferior conjunction, it is so near to the ecliptic that to an observer on the earth's surface it appears projected on the sun's disc. Let V represent the centre of the planet. The observer at the station O will see the planet projected on the sun's disc at Y; the observer at P will see it projected on the solar



disc at X. The result, consequently, is, that as the planet travels in its orbit towards Z, the observer at O will see it traversing the chord C Y D of the solar disc; while, on the other hand, the observer at P will see it traversing the chord F X H. Now X Y, which measures the linear breadth of the zone included between these chords, is known, for it exceeds the line joining O P in the proportion of the distance between the sun and Venus to the distance

between Venus and the earth—that is to say, in the proportion of 72 to 28. Again, the angular diameter of the sum is known from instrumental measurement. It is clear, then, that if we knew the angular breadth of the zone included between the chords C Y D, F X H, or, in other words, if we knew the proportion which the angular breadth of the zone bears to the whole apparent diameter of the sun, we should be enabled to determine by a process of simple proportion the absolute diameter of the sun, and hence, knowing already the apparent diameter of that body, we should finally arrive at a knowledge of its distance, and consequently its horizontal parallax.

The solution of the problem plainly depends, therefore, on the determination of the angular breadth of the zone included between the chords C Y D, F X H. Now the breadth of this zone may obviously be derived from the length of the chords C Y D, F X H, relatively to the apparent diameter of the sun. But the motion of the planet being known, the length of either of the chords will be indicated by the time which the planet occupies in passing from one extremity of the chord to the other. The problem is, therefore, finally reduced to the observation of the times occupied by the planet in traversing the chords C Y D, F X H, as seen from the two stations O and P.

In the explanation just given we have not taken account of the earth's orbital motion. It is to be borne in mind, however, that when Venus is in inferior conjunction, it is travelling in the same direction as the earth, but, being nearer the sun than the earth, its motion is quicker, and the result is that it apparently travels over the sun's disc with a velocity equal to the excess of its orbital motion over that of the earth. Hence the explanation of its transit will obviously be sufficient, if we suppose the earth to be at rest, and the planet to be travelling over the sun's disc merely with its relative motion. It may be remarked, further, that the time of the transit is materially influenced by the earth's rotation on its axis. We have not, however deemed it necessary to enter into all the niceties of this celebrated problem, but have endeavoured merely to give a general idea of the principle of the method of solution.

In 1761 and 1769 there occurred transits of Venus, on each of which occasions the principal Governments of Europe despatched observers to different parts of the world both in the northern and the southern hemispheres, who noted at their respective stations the time occupied by the planet in traversing the sun's disc. From the materials thus collected the late distinguished astronomer, Professor Encke, determined the horizontal parallax of the sun to be 8".57. This value, it will be seen, does not agree with that derived from observations of Mars. The researches of astronomers derived from other sources would seem to indicate that the latter value—namely, 8".95—is the more accurate of the two. The value 8".57 has been deduced chiefly from the transit of Venus, which occurred in 1769, the observations of which in the northern hemisphere have been considered defective. In the years 1874 and 1882 there will again occur transits of the planet, the observations of which, it may be expected, will lead to a definitive determination of the solar parallax. In the mean time, the result derived from recent researches—namely, 8".95—has been adopted by astronomers as the most trustworthy value of that element. It is, accordingly, the value which has been employed in computing the various numerical results depending on the solar parallax which are given in this explanatory work.

CHAPTER X.

The Sun—Elements of its Orbit—Variation of Apparent Diameter—Distance from the Earth—Solar Spots—Rotation of the Sun—Periodicity of the Spots—Physical Constitution of the Sun.

The sun, which exercises so genial an influence on the animal and vegetable productions of the earth, must naturally have been an object of much interest to astronomers in all ages. The attention of the Greek astronomers was confined exclusively to an investigation of the facts relating to its apparent motion in the heavens. They did not fail to discover that the supposition of the sun revolving uniformly in a circular orbit round the earth in the centre was irreconcilable with the results of observation. Hence originated the epicyclical theory which placed the earth in a position a little excentric with respect to the orbit in which the sun revolved. The amount of this excentricity constituted one of the elements of the solar orbit. But the excentricity of the orbit implied a variation of the sun's distance from the earth, and suggested the determination of the direction of the line joining the points of least and greatest distance. This constituted the second element of the solar orbit. The other two elements, the length of the year and the mean longitude of the sun, corresponding to a given epoch, were also determined by the Greek astronomer Hipparchus with considerable precision, and upon the aggregate results thus obtained the earliest tables of the sun's motion were constructed.

In the Copernican system of the universe the orbit which the sun apparently describes in the heavens is merely an optical illusion due to the real motion of the earth round the sun. It has been further established by astronomical researches that the orbit, whether apparent or real, is an ellipse, the earth occupying the focus in the one case and the sun in the other.

The variable distance of the sun as it revolves in its annual orbit is clearly indicated by observations of its apparent diameter. As the distance of the sun from the earth increases the apparent diameter necessarily diminishes, and *vice versâ*. Now, it is found by actual measurement that the apparent diameter of the sun is perpetually varying throughout the year. It is greatest on the 31st of December, when it amounts to $32' 36''.4$, and least on the 3d of July, when it measures only $31' 32''$. It follows, therefore, that the sun is nearest to the earth on the 31st of December, and most distant from it on the 3d of July. If we suppose the mean distance of the sun to be represented by 10,000, the greatest distance will be represented by 10,168, and the least distance by 9832.

It may naturally be asked, how does it happen that it is hottest when the sun is most distant from the earth, and coldest when it is nearest to our planet? The reason of this is simple enough. In summer the sun, although distant, rises high and remains long above the horizon; in winter, although nearer, its height is inconsiderable, and it remains only a short time above the horizon. It results, indeed, from the laws of the diffusion of heat and of the angular motion of the sun round the earth, that the variation of the sun's distance exercises only an inconsiderable influence on the heating of the earth's surface; for when the sun is nearest, and consequently most favourable for the diffusion of heat, its angular velocity is greatest; and on the other hand, when it is most distant and least favourable for the diffusion of heat, its angular velocity is least. The sun, therefore, dwells a *shorter* time in the half of its orbit which is more favourable to the heating of the earth's surface, and dwells *longer* in the half which is less favourable to that object, and a compensation is thus effected which almost entirely neutralises the influence due to the variation of the sun's distance.

The absolute distance of the sun from the earth is 91,200,000 miles. Its absolute diameter measures 850,000 miles, a result which, in round numbers, exceeds the earth's diameter in the proportion of 108 to 1. Consequently in volume the sun exceeds the earth in the proportion of 1,259,712 to 1.

When the sun is viewed with a telescope there appear numerous dark spots on its surface. These spots are very irregular both in form and magnitude. They generally consist of a dark central nucleus, surrounded by a less obscure region termed the penumbra. Their structure is subject to rapid and extensive fluctuations. Sometimes a large spot will be seen to break up into several detached spots. On other occasions several contiguous small spots will coalesce and form one great spot. An attentive observer of the spots will not fail to discover changes of this kind even in the course of a single day.

When a spot has been observed for several days in succession, it is found to be gradually travelling from left to right on the sun's disc, until it finally disappears at the western limb. A careful comparison of such observations has led to the important discovery that the sun has a motion of rotation on a fixed axis. According to the most recent researches, the inclination of the solar equator to the ecliptic is 7° 15′, and the longitude of the ascending node is 73° 40′. These elements have been assigned by Mr Carrington, in his elaborate work on the solar spots as applicable to the year 1850. The time of rotation has been determined to be 25 days, 7 hours, 48 minutes. These results are all liable to a considerable degree of uncertainty in consequence of the solar spots being affected with a proper motion independent of the sun's rotation.

If the plane of the solar equator coincided with the plane of the ecliptic, the apparent path of a spot across the sun's disc would invariably be a straight line. Since, however, the two planes are inclined to each other at an angle of more than 7°, it results that the apparent path of a solar spot is generally of an elliptical form. In June the plane of the solar equator passes through the earth, and the apparent path of the spot is then a straight line. During the next six months, however, the north pole of the sun is turned towards the earth, and the paths of the spots are ellipses with the convexity turned downwards, the minor axis being greatest in September, when the north pole is turned the greatest possible towards the earth. In December the plane of the solar equator again passes through the earth, and the apparent paths of the spots become straight lines. Henceforward till June the same succession of changes ensues in a reverse order. The south pole is now turned towards the earth, and the apparent paths of the spots are ellipses with their convexity turned upwards, the minor axis being greatest in March, when the south pole is turned towards the earth as much as possible. The various forms which the apparent path of a solar spot thus presents in the course of a year are exhibited in Plate 3.

The spots generally appear in groups, and are confined to a region extending about 35° on each side of the solar equator. It has been already remarked that they fluctuate very much in form and magnitude. The same is true with respect to their paucity or abundance. On some occasions not one spot is visible on the solar disc. At other times the whole of the region in which they usually appear is thickly strewed with them.

Schwabe, a German astronomer, has found that the number of spots visible on the sun's disc recur in periods of somewhat more than ten years. It has since been discovered that the variations of terrestrial magnetism are characterised by a period of equal duration.

Many of the solar spots are of great magnitude. Frequently they have a diameter of two or three minutes, and when seen through a hazy atmosphere have been visible to the naked eye.

Besides the spots, there are patches of light on the sun's disc which are more luminous

than the general surface. These have been termed *faculæ*. They generally are seen in the vicinity of extensive groups of spots.

In recent years the observations of the luminous surface of the sun have revealed a curious phenomenon in the existence of a number of objects of determinate form and magnitude spread over the entire surface, and suggesting in the outlines of their structure a resemblance to *willow leaves*. Observers are not yet agreed on the question whether such phenomena are distinct entities now discovered for the first time, or whether they are merely modifications of some of the ordinary phenomena exhibited by the solar photosphere.

The spots are cavities in the sun's surface. This has been established beyond all doubt by the observations made by Dr Wilson of Glasgow towards the close of the last century. Nothing definite beyond this has heretofore been made out respecting them. That the nuclei of the spots are portions of the dark body of the sun revealed to us by rents in the photosphere seems highly probable, but how the spots are generated, and what is the origin of the characteristics which they exhibit, are questions involved in profound mystery.

In recent years photography has been applied with great success at the Observatory of Kew to the delineation of the solar spots. An instrument has been expressly fitted up in connection with this object, and every day on which the sun is visible a picture of its surface is taken by the agency of its own light. Important results may hereafter be expected from a discussion of the accumulated results of such observations.

In Plate 3, the solar disc is represented as seen under a low magnifying power. In the same Plate are seen, on a portion of the disc, several solar spots as viewed with a high magnifying power, accompanied by numerous faculæ.

The recent researches in spectral analysis have thrown some important light on the question of the physical structure of the sun. According to the conclusions arrived at, the sun is to be regarded as an incandescent body, surrounded by an atmosphere of a somewhat lower temperature, in which are contained vapours of sodium, iron, magnesium, and certain other substances (see Chapter XVIII.) Of the existence of an atmosphere about the sun, the phenomena seen during total eclipses of that body afford very strong proof. We shall have occasion hereafter to refer to this subject.

The question with respect to the source of the solar heat is involved in profound mystery. It has been supposed in recent times, by Sir William Thomson and others, that it may have originated from the friction occasioned by a zone of meteors circulating in the solar atmosphere round the sun, and falling gradually in upon its surface.

In Plate 3 we have a representation of the apparent magnitude of the sun as viewed from the different planets. To an observer on Mercury the sun would present an apparent diameter of not less than a degree and a half; as the distance of each planet increases, the apparent diameter of the sun diminishes, until at length, to an observer on the surface of Neptune, the apparent diameter of the sun would not exceed 1′; in other words, the sun would exhibit merely the apparent magnitude which the planet Venus presents to an observer on the earth at the time when it is approaching the position of inferior conjunction.

CHAPTER XI.

The Moon—Its Distance and Magnitude—Sidereal and Synodic Revolutions—Variation of apparent Diameter—Motion of the Nodes and Apsides—Explanation of its Phases—Origin of the *Lumière cendrée*, or ashy Light—Mountains of the Moon—Physical Constitution.

The moon stands in the relation of a satellite to the earth, accompanying it in its annual motion round the sun, and at the same time revolving round it in a monthly orbit. The mean distance of the moon from the earth amounts to 238,750 miles. Its linear diameter measures 2150 miles. In considering the revolution of the moon round the earth, there exists the same distinction between the sidereal and synodic revolutions as holds in the case of the planets. The moon travels in the heavens from west to east; that is to say, in the same direction as the sun and planets, accomplishing a complete revolution round the earth with respect to the stars in 27 days, 7 hours, 43 minutes, 11 seconds. This is accordingly denominated the time of a sidereal revolution of the moon. But while the moon has thus been revolving in its monthly orbit, the sun has been travelling in the same direction in its apparent annual orbit. The result, consequently, is, that when the moon has completed its sidereal revolution round the earth, the sun has advanced in its orbit a certain angular distance to the eastward of the position which it occupied at the commencement of the moon's revolution; and in order that the two bodies should again occupy the same relative position which they originally did, it is necessary that the moon should advance somewhat further in its orbit; hence originates the idea of a synodic revolution of the moon, which represents the time included between two consecutive returns of the sun and moon to the same relative position. The time of a synodic revolution of the moon amounts to 29 days, 12 hours, 44 minutes, 3 seconds.

The orbit in which the moon revolves round the earth is an ellipse, having the earth in one of the foci. It has been found by observation that the major axis of this ellipse is not stationary. According to the researches of astronomers, its extremities, or the points of least and greatest distance from the earth, in other words, the perigee and apogee, are continually advancing in the direction of the moon's motion, effecting a complete circuit of the heavens in 3222 days, 13 hours, 56 minutes, 16.8 seconds, or somewhat less than 9 years.

The excentricity of the solar orbit is small, and sensibly invariable. The excentricity of the lunar orbit, on the other hand, is considerable, and is subject to extensive variations from the disturbing influence of the sun's attraction. It happens, in consequence, that the least and greatest distances of the moon from the earth vary relatively to each other much more extensively than do the corresponding distances of the sun from the earth. Thus, while the least and greatest distances of the sun from the earth are only in the proportion of 30 to 31, the least and greatest distances of the moon are in the proportion of 7 to 8. Hence also the least and greatest apparent diameters of the moon are in the same proportion, with this difference only, that when the distance is greatest the apparent diameter is least, and *vice versâ*. Thus, when the moon is at her least perigean distance, her apparent diameter amounts to 33′ 31″; on the other hand, when she is at her greatest apogean distance, her apparent diameter measures only 29′ 22″.

The orbit of the moon is inclined to the ecliptic at an angle of 5° 8′. While the moon revolves in the direction of the signs of the zodiac, the points of intersection of its orbit and the ecliptic, in other words, the nodes of the lunar orbit, retreat in the opposite direction. In

virtue of this retrograde movement the lunar nodes effect a complete revolution in the heavens in 6793 days, 10 hours, 6 minutes, 30 seconds, or somewhat more than 18 years.

One of the most interesting features of the moon consists in the variety of phases which it exhibits. The phenomenon is very satisfactorily explained by the circumstance of the moon being an opaque body, which shines only by the reflected light of the sun. Thus, when the moon is in conjunction with the sun, the illuminated half of its surface is turned wholly away from the earth, and it is consequently invisible. This is the instant of new moon. As the moon advances in its orbit the illuminated hemisphere is gradually turned towards the earth, and it exhibits the form of a crescent, increasing in breadth every evening. When it has completed a quarter of a synodic revolution, the half of the illuminated hemisphere is turned towards the earth, and it exhibits the form of half moon. During the next quarter of a revolution the illuminated half of its surface continues to be turned gradually more and more towards the earth, and it presents what is called the gibbous phase. When it has completed the half of a synodic revolution, so as to appear in the opposite region of the heavens to that in which the sun is situated, the illuminated half of its surface is turned wholly towards the earth, and it exhibits a full orb of light; this is the time of full moon. During the remaining half of the synodic revolution the same succession of phases ensues in a reverse order. This beautiful phenomenon of the moon's phases is illustrated in fig. 6, Plate 1.

In connection with the moon's phases, another interesting phenomenon occurs to observation. When the moon is only a few days old, so as to exhibit merely a slender crescent of light, the remainder of its disc is distinctly visible by a faint light. The origin of this curious appearance was long involved in mystery, until it was shown by Mæstlin, a German astronomer, to arise from the reflected light of the earth falling upon the moon's dark surface, and thereby rendering it visible. To understand the true import of this explanation, it is necessary to bear in mind that about the time of new moon the illuminated half of the earth's surface is turned almost wholly towards the unenlightened surface of the moon. As the moon, however, advances in its orbit, the earth's illuminated hemisphere is gradually turned away from it, and the dark part of its surface gradually receives less and less of *earth-light*. Hence arises the circumstance of the phenomenon being most distinctly visible when the moon is only a few days old.

The moon has a motion of rotation on a fixed axis, which is nearly perpendicular to the plane of its orbit. It effects a complete rotation round this axis in the same time which it occupies in revolving round the earth. Hence it follows that the moon always presents the same hemisphere towards the earth.*

The surface of the moon, when examined with a telescope, is found to present numerous indications of ruggedness. The boundary which separates the illuminated from the non-illuminated part of the disc, instead of being a uniform line of light, as it would be if the surface was perfectly smooth and level, presents everywhere a jagged appearance. Isolated specks of light may be seen everywhere along the boundary of light and darkness, affording unequivocal indications of the existence of lofty mountains, the summits of which reflect the rays of the rising or setting sun, while the intervening valleys lie buried in darkness. The entire illuminated part of the disc offers similar evidence of the general unevenness of the moon's surface. One of its most striking features consists in the existence of immense numbers of mountains of a circular form, distributed over the whole surface, and exhibiting every gradation of magnitude. That they are mountains is proved from the shadows which they cast in each instance upon the interior basement, and which increase or diminish in length according as the sun is less or

* Strictly speaking, the moon is subject to a small libratory movement, in virtue of which we are enabled to see alternately, at opposite sides of the disc, a narrow strip of the hemisphere usually turned away from the earth.

more elevated with respect to the horizon. These innumerable craters offer indubitable evidence of extinct volcanic action. In many instances there is to be seen in the centre of the crater a small eminence which has been considered with high probability to indicate the expiring efforts of the volcanic force.

Besides the ring-shaped mountains, there are numerous mountain-ranges distributed over the entire surface of the moon. Some of these mountains are of great height, as will be seen by the following few instances extracted from the list of their measured altitudes :—

	Feet.		Feet.
Doerfel, ...	24,945	Calippus, ...	20,394
Leibnitz, ...	24,935	D'Alembert, ...	19,183
Newton, ...	23,833	Caucasus, ...	18,265

It appears from these examples that the mountains of the moon are relatively much higher than those on the earth's surface.

The application of photography to the delineation of the moon's surface has been brought to a high state of perfection in recent times by De La Rue, Secchi, and Rutherford.

Plate 4 exhibits several views of the moon's surface. In the upper corner to the left is a representation of the celebrated Crater of Copernicus, from an orginal drawing by Padre Secchi. The diameter of this crater measures 54 miles. The surrounding ring mountain rises to an altitude of 11,000 feet above the level of the base. In the upper corner to the right is a photographic view of a portion of the moon's surface, also by Padre Secchi. The shadows cast by the ring mountains are here shown very distinctly. In the centre is a view of the full moon, from a drawing by Bode. Towards the upper part of the disc may be seen the striking spot called Tycho. Lines of light may be seen radiating from it in all directions. No satisfactory explanation has been given of the origin of these luminous rays. That they are not streams of any fluid is proved by the fact of their passing over the summits of intervening mountains. They are most probably fissures in the moon's surface, occasioned by the upheaving force of the volcanic fluid.

The remaining figures of Plate 4 indicate the appearance presented by the moon in different stages of her illumination.

The darker portions of the moon's disc have been denominated seas, but this is merely a fanciful nomenclature, for there are no indications of the existence of any fluid on the moon's surface. Indeed, the most probable opinion seems to be that the moon, being a smaller body than the earth, has cooled down more rapidly than its primary, and the result is that all the gaseous and fluid substances on its surface have ultimately assumed a perfectly solid state, while the earth is still encompassed by an atmosphere, and the greater portion of its surface is covered by an aqueous fluid.

CHAPTER XII.

Eclipses of the Sun.

Circumstances which determine a Solar Eclipse.—We have seen that the apparent diameters of the sun and moon are on the whole nearly equal in magnitude; for although the sun vastly exceeds the moon in absolute dimensions, its distance from the earth exceeds the moon's distance nearly in the same proportion. The greatest and least apparent diameter of the sun are 32′ 35″ and 31′ 30″. The greatest and least apparent diameters of the moon are 33′ 31″ and 29′ 22″. These limiting values play an important part in the theory of solar eclipses.

If the moon, in the course of its revolution round the earth, should happen to be directly interposed between the earth and the sun, and if, at the same time, its apparent diameter should exceed in magnitude the apparent diameter of the sun, it would wholly prevent the solar light from reaching the earth, and a *total eclipse* of the sun would necessarily ensue. If, on the other hand, the apparent diameter of the moon fell short of the sun's apparent diameter, the moon would not wholly cover the sun's disc, but would leave exposed on all sides a narrow ring of light. In this case there would occur the beautiful phenomenon of an *annular eclipse* of the sun.

The occurrence of a total or annular eclipse of the sun necessarily implies that the centres of the two bodies are situated in the same direction, or at any rate very nearly so. If, however, at the time of conjunction the moon should be a little higher or a little lower than the sun, it will merely cover a portion of the solar disc, and a *partial eclipse* of the sun will be the result.

If the moon revolved in the plane of the earth's orbit, it would come directly between the earth and the sun once in every month, and an eclipse of the sun, whether total, annular, or partial, would be the necessary consequence. This is not, however, the real state of matters. The orbit of the moon is inclined to the ecliptic at an angle of somewhat more than 5°. The result consequently is, that unless the moon should happen to be near either of the points of intersection of its orbit with the ecliptic—in other words, unless it should happen to be near either of its nodes—it will not be directly interposed between the earth and sun, and consequently an eclipse will not occur.

Chaldean Cycle of Eclipses.—A remarkable relation exists between the mean motion of the moon's nodes and the mean synodic revolution of the moon round the earth, which occasions a regular recurrence of eclipses in a cycle of somewhat more than eighteen years. In a period of 6585.772 days the moon's nodes return to the same position with respect to the sun. On the other hand, 223 synodic revolutions of the moon include a period of 6585.321 days. Hence when a cycle of 6585.321 days has been completed, the moon will have returned to the same position with respect to the sun, and in barely twelve hours afterwards will have occupied the same position with respect to the node. This cycle of 18 years 10 days 7 hours 43 minutes, which brings about a regular recurrence of eclipses, was originally discovered by the Chaldeans.

The occurrence of a total eclipse of the sun at any particular place of the earth's surface is necessarily very rare. This will be easily understood when we consider that the diameter of the moon's shadow does not in any case exceed 190 miles, and that in consequence of the earth's rotation the moon's shadow may fall on very different parts of the earth's surface at the corresponding epochs of two successive cycles.

The duration of a total eclipse is generally very short. Under any circumstances it cannot exceed 7 minutes 38 seconds. The greatest eclipse recorded in the annals of astronomy is one which occurred on the 17th of August 1868, and which was visible in India. The totality lasted in some places nearly six minutes.

Figure 7, Plate 5, represents the moon's shadow falling upon the earth, and causing a total eclipse of the sun. The shadow, it will be seen, is conical. The less shaded region exterior to the limits of the shadow is termed *the penumbra*. To persons situated within this region, the sun will appear partially eclipsed. In fig. 8, the moon's shadow falls short of the earth's surface. The result is, that the diameter of the moon will not cover the whole body of the sun, but a ring of light will appear all around its dark limb, occasioning the phenomenon of an annular eclipse. The base of the dark cone which falls upon the earth represents the

region wherein the eclipse will present an annular aspect. The faint space beyond indicates the region wherein the sun will appear partially eclipsed.

Appearances during a Total Eclipse.—During the obscuration which characterises a total eclipse of the sun, the dark body of the moon appears encompassed by a halo of pale light, from which there extend rays in all directions, somewhat resembling the *glory* with which painters in catholic countries surround the heads of the saints. There are also generally visible certain rose-coloured prominences either in apparent contact with the moon's limb or immediately contiguous to it. Figures 1, 2, 3, Plate 5, represent the phenomena observed during the total eclipses of 1851, 1842, and 1858.

The Red Prominences proved to be Solar Phenomena.—It was long uncertain whether the red prominences seen during total eclipses of the sun are solar or lunar phenomena. The observations of the eclipse of 1851 seemed to lead to the conclusion that they in reality belong to the sun. This view of the question was also supported by similar observations of the total eclipse which occurred in Spain on the 18th of July 1860; but it was for the first time made manifest to every person by the results of photographic delineations of that eclipse taken with complete success by Mr Warren De La Rue. Figures 4, 5, and 6, Plate 5, are copies of photographic views taken by Mr De La Rue at the beginning, in the middle, and at the close of the totality. The moon is supposed to travel from right to left over the sun's disc. Hence it is plain that if the prominences belonged to the sun, those on the left of the moon's limb would be visible at the commencement of the totality; while, on the other hand, at its close, those on the right would appear uncovered; and the disappearance of the prominences in the one case and their appearance in the other would be gradually developed by the progress of the eclipse. This is the result which Mr De La Rue's photographs reveal, as may be readily seen by a simple inspection of figures 4, 5, and 6.

Observations of the spectra of the prominences, obtained in India during the total eclipse of 1868, August 17, would seem to indicate that they are of gaseous structure. (See Chap. xviii.)

CHAPTER XIII.

Eclipses of the Moon.

Circumstances which determine a Lunar Eclipse.—The earth being a globular body, greatly inferior in magnitude to the sun, the shadow which it casts by intercepting the sun's rays is necessarily of a conical form. But the distance between the earth and the sun being very great, the bounding lines of this cone converge very slowly, and hence the shadow extends to a considerable distance beyond the earth. The axis of the shadow exceeds the earth's radius in the proportion of 220 to 1 nearly. On the other hand, the moon's mean distance from the earth exceeds the earth's radius in the proportion only of 60 to 1. It is evident, therefore, that if the moon, in the course of its revolution round the earth, should at any time approach very near the ecliptic, it must wholly or partially enter the earth's shadow, and an eclipse of the moon, whether total or partial, will be the result. The question whether the moon may at any time be wholly immersed in the earth's shadow, depends obviously on the relative dimensions of the moon and the shadow. Now, at the mean distance of the moon, the radius of the shadow is to the earth's radius as 8 to 11; but the radius of the moon is to

the earth's radius only in the proportion of 3 to 11. Hence the radius of the shadow exceeds the moon's radius in the proportion of 8 to 3; and, consequently, if the moon should be in the plane of the ecliptic, or very near to it, at the time when the earth is interposed between it and the sun—in other words, at the time of opposition or full moon—it will necessarily undergo a total eclipse.

If the moon at the time of opposition should be in either of its nodes, or very near thereto, it will undergo a total eclipse. If at the time of opposition its distance from the node does not exceed 9° 20′ 29″, it cannot fail to enter the earth's shadow, whether wholly or partially, and a total or partial eclipse will be the result. Even if its distance from the node should not exceed 11° 25′ 40″, it may, under certain circumstances, depending on the distances of the sun and moon from the earth, undergo a partial eclipse. The greatest possible duration of a total eclipse of the moon is about two hours.

Fig. 2, Plate 6, exhibits three different cases of the relative positions of the moon and the earth's shadow. In the dark circle to the right, the moon, being supposed in the node or very near thereto, is wholly immersed in the earth's shadow, and consequently undergoes a total eclipse. In the second case, its distance from the node is too great to admit of a total immersion in the shadow, but a portion of the disc enters into it, and a partial eclipse is the result. In the third case, the one to the extreme left, the distance from the node at the time of opposition is so great that the moon wholly escapes the earth's shadow, and there is consequently no eclipse.

In fig. 1, Plate 6, there may be seen a faintly-shaded space extending on each side beyond the earth's shadow. This is called *the penumbra*. During a total eclipse the moon first enters the penumbra and then the shadow properly so called. On emerging from the shadow, it re-enters the penumbra, which it finally quits at the opposite limb.

Visibility of the Moon's Surface during a Total Eclipse.—In general the moon does not cease to be visible to an observer on the earth's surface, even when it is wholly immersed in the earth's shadow. This arises from the circumstance that the sun's rays in passing through the earth's atmosphere are bent inwards by refraction to such an extent that although the earth is directly interposed between the sun and moon, they fall upon the moon's surface, and render it faintly visible. Most frequently during the totality of a lunar eclipse the moon's surface exhibits a dull copper colour, an effect attributable to the greater momentum with which the red rays of the solar spectrum traverse the earth's atmosphere. Fig. 3, Plate 6, exhibits the appearance presented by the moon during the total eclipse of March 19, 1848. During the partial eclipse of March 8, 1849, the moon's disc assumed an olive-green colour, as represented in fig. 4, Plate 6. The varying appearances which the moon's surface exhibits on such occasions depend evidently on the physical changes perpetually occurring in the earth's surface.

CHAPTER XIV.

The Planets.

General Survey of the Planetary System.—The planetary system, as at present known to astronomers, consists of eight principal planets, viz. Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, and Neptune, besides the group of minor planets revolving between Mars and Jupiter, which now amount to 106, and the number of which is increasing every year. Moreover, several of the planets are accompanied by satellites. Thus, the Earth is accompanied by one satellite, Jupiter by four, Saturn by eight, Uranus by four, and Neptune by one. The aggregate number of satellites at present known to exist amounts, therefore, to eighteen.

The planets may be divided into three classes. First, there are the four interior planets, Mercury, Venus, the Earth, and Mars. These bodies are all of moderate dimensions, are nearly equal in density, and, except in the case of the Earth, are unaccompanied by satellites. Then there is the group of minor planets, which are distinguished by their excessive smallness, and by all revolving within a comparatively narrow zone of the planetary regions. Finally, there are the four exterior planets, which are distinguished by their immense magnitude, by their moderate density, and by the circumstance of their being in every instance accompanied by one or more satellites. A view of the Planetary System is given in Plate 7. We proceed to give a brief description of the various bodies of the system, commencing outwards from the Sun.

Mercury.—The planet Mercury, when favourable for observation, may be seen shining as a brilliant star in the west a little after sunset or in the east a little before sunrise. Its mean distance from the sun is 35 millions of miles. Its orbit, however, being considerably excentric, its real distance from the sun is liable to vary to a corresponding extent in the course of a revolution. It is found, in fact, that the perihelion distance is 28 millions of miles, while on the other hand the aphelion distance amounts to 43 millions of miles. The greatest distance of the planet from the earth is 133 millions of miles; the least distance is 58 millions of miles. The least and greatest apparent diameters are 4".5 and 12".5. The real or linear diameter is 2964 miles. When viewed with a telescope, Mercury exhibits phases like the moon, depending on its position relatively to the earth and the sun. This proves that it is an opaque body like the earth, shining only by the reflected light of the sun.

Since Mercury revolves within the earth's orbit, it might be expected occasionally to come directly between the sun and the earth, and to appear as a black spot passing over the sun's disc. This would occur in the course of each synodic revolution of the planet if it revolved in the plane of the ecliptic. Since, however, the orbit of the planet is inclined to the plane of the earth's orbit at a considerable angle, it is only upon certain rare occasions—when, in fact, the planet is passing through either of the nodes of its orbit—that it appears projected on the sun's disc like a round black spot. Phenomena of this nature, as already remarked in a preceding Chapter, are termed *transits* of the planet over the sun's disc. They occur at intervals of several years. The French astronomer Gassendi was the first who observed Mercury upon the sun. This was in the year 1631. Plate 9 contains a graphic representation of the apparent paths of the planet over the sun's disc for the various transits of the nineteenth century.

Venus.—This is the most brilliant of all the planets. Its mean distance from the sun is 66 millions of miles. The orbit of the planet being only slightly elliptical, the variations of its

distance from the sun are inconsiderable. On the other hand, since it approaches nearer to the earth's orbit than any of the other planets, its distance with respect to the earth is liable to extensive variations. Its maximum distance from the earth, which it attains upon arriving in superior conjunction, is 157 millions of miles. Its maximum distance, corresponding to its arrival in inferior conjunction, is only 25 millions of miles. The diameter of this planet is 7500 miles.

When Venus is passing from superior to inferior conjunction, it follows the sun, and is visible in the western sky after sunset. On the other hand, when it is passing from inferior to superior conjunction, it precedes the sun, and is therefore visible in the morning before sunrise. It is on this account that the planet is termed alternately *the morning and evening star*.

When the planet is travelling from superior to inferior conjunction—in other words, when it is an evening star—it appears to the east of the sun; and when the angular distance from that body has attained its maximum value (which generally amounts to about 48°), the planet is then said to be at its greatest *eastern* elongation. Shortly after the passage of inferior conjunction, it begins to appear to the *west* of the sun, being visible as a morning star a little before sunrise. As it continues to travel in its orbit the angular distance from the sun increases every night, and when it has receded as far as possible, it is then said to be at its greatest *western* elongation. Henceforward it approaches the sun, and finally rises and sets with that body when it again arrives in superior conjunction.

The planet attains its greatest brilliancy as an evening star when it arrives in a certain determinate position, situated between its greatest eastern elongation and inferior conjunction. Similarly it attains its greatest brilliancy as a morning star a little before it arrives in the position of greatest western elongation. About the time of greatest brilliancy, whether as a morning or an evening star, the planet may be distinctly seen with the naked eye in the daytime for several weeks in succession.

One of the first fruits of Galileo's application of the telescope to astronomical observation consisted in his discovery of the interesting fact that Venus exhibits phases like the moon. This proved that the planet, like the earth, is indebted to the sun for the light by which it shines; and in so far it supplied a strong confirmation of the Copernican system of the universe. Plate 9 exhibits telescopic views of the planet when it resembles the half-moon, and when it presents the form of a crescent.

It has been already remarked in a preceding section that on certain rare occasions Venus may be seen as a round black spot traversing the sun's disc. A view of the transits of 1874 and 1882 is given in plate 9, accompanied in each instance with a view of the illuminated hemisphere of the earth at the ingress and egress of the planet.

The Earth.—The mean distance of the earth from the sun is 91,200,000 miles. The greatest distance is 92,723,000 miles. The least distance is 89,669,000 miles. It has been already remarked that the figure of the earth is that of an oblate spheroid which is flattened at the poles. The most recent researches of astronomers on this subject lead to the following results:—

	In Feet.	In Miles.
Equatorial Diameter, ...	41,852,696	7926.1
Polar Diameter, ...	41,710,466	7899.0
Difference, ...	142,230	27.1

Proportion of diameters as 294.3 to 293.3.

The spheroidal figure of the earth is due to the centrifugal force generated by the diurnal

rotation. If we suppose the earth to have been originally in a fluid state, the effect of such a force would be to heap up the waters at the equator by drawing them from the regions around the poles, and the figure of equilibrium which the earth would assume under such circumstances would continue to exist when the earth finally assumed its present condition of a solid body partially covered by an aqueous fluid. In fact, it appears from the foregoing numbers that the waters of the ocean are piled up at the equator thirteen miles higher (relatively to the earth's centre) than they are at the poles; and if it were not for the continual rotation of this mass of fluid round the earth's axis it would flow towards the poles and submerge the whole surface of the earth.

The slow conical motion of the earth's axis which produces the phenomenon of the precession of the equinoxes is due to the disturbing forces which the sun and moon exercise upon the redundant matter accumulated round the earth's equator. The discovery of this grand fact, and its rigorous demonstration by the principles of physical astronomy, constitute one of the most remarkable triumphs of the genius of the immortal Newton.

The Tides.—The phenomena of the Tides arise from the combined attraction which the sun and moon exercise upon the aqueous fluid with which the earth's surface is partially covered. The effect produced by the action of either of those bodies is to heap up the waters of the ocean in the direction of the disturbing body, and also in the opposite direction, so as to cause the earth to assume the form of an ellipsoid (neglecting the inequalities of the surface), the longer axis being directed towards the disturbing body.

The moon produces a greater effect in the production of the tides than the sun does, for although its mass is excessively small relatively to the sun's mass, it is immensely nearer to the earth; and the advantage which it derives as an attracting body from this circumstance, more than compensates for its inferiority in respect to the quantity of attracting matter. When the forces of the sun and moon act in the same straight line, which they invariably do at the times of new and full moon, the combined effect of the two disturbing bodies is the greatest possible. The tides at such junctures are termed *spring tides* (see fig. 4, Plate 2). In every other position of the moon with respect to the sun, the forces of the two disturbing bodies, by acting more or less in different directions, tend to neutralise each other, and the combined effect is a minimum when the two bodies act in directions at right angles to each other, which obviously happens when the moon is in the first or last quarter. The effect produced in such cases is merely the excess of what results from the moon's disturbing action over what is due to the sun's. At such junctures the phenomena are termed *neap tides* (fig. 3, Plate 2).

Lagging of the Tidal Wave.—Generally the longer axis of the tidal wave lags somewhat behind the disturbing body, for the inertia of the waters of the ocean offers an effective resistance to the immediate action of the disturbing force. The result is, that high water at any place does not occur when the moon (which, being the principal disturbing body, regulates the course of the phenomena) is actually on the meridian, but about two hours afterwards.

Some persons who readily understand how the sun or moon produces a tide on the earth's surface in the direction in which the disturbing body is situated, experience a difficulty in reconciling with their ideas of attraction the existence of a tidal wave in the opposite direction relatively to the earth's centre. The difficulty will be obviated, however, if it be borne in mind that the disturbing body acts upon the solid as well as the fluid parts of the earth, and with an intensity which is inversely proportional to the square of the distance between it and the matter attracted. The disturbing body heaps up the waters immediately under it, because, being nearer to them, it attracts them with greater intensity than it does the rest of the earth's mass. On the other hand, the waters at the opposite side of the earth, being more distant than the

rest of the earth's mass, are attracted with less intensity, and are consequently *left behind*, which is of course tantamount to a heaping-up of the waters.

Mars.—This planet is distinguishable by its fiery red colour. Its mean distance from the sun is 138,990,000 miles; the perihelion distance is 126,040,000 miles; the aphelion distance is 151,940,000 miles.

The orbit of this planet being considerably excentric, and its perihelion coinciding nearly in direction with the aphelion of the earth's orbit (supposing both to be referred to the sun), it results that the planet on some occasions approaches, comparatively speaking, very near to the earth. Thus, for instance, in the autumn of 1862, the distance of Mars from the earth at the time of opposition amounted to only 34.7 millions of miles. The occurrence of such near approaches of the earth and planet is extremely favourable for the determination of the solar parallax by the method explained in Chapter IX. The next favourable occasion for this purpose will occur in the year 1877, when the distance between the two bodies at the time of opposition will be only 33.7 millions of miles.

The diameter of Mars is about 3950 miles. When viewed in the telescope the surface of the planet appears much diversified, suggesting a strong resemblance in this respect to the earth. By watching some of the spots visible on its surface it has been discovered that the planet revolves upon an axis in the same direction as the earth. The time of rotation has been found to be 24h. 37m. 23s. A telescopic view of the planet is given in Plate 9.

Physical Constitution.—It is very probable that Mars, like the earth, is surrounded by an atmosphere, although no direct proof of the existence of such has yet been discovered. The varied aspect of the surface would seem to be favourable to the supposition of the planet being encompassed by clouds. Still further evidence is afforded by the appearance of white spots near the poles, which have been supposed with strong probability to be snow, inasmuch as they are found to vanish when they have been long exposed to the sun's rays, and, on the other hand, are usually most extensive when the polar winter is about closing. A view of these spots is given in the figure of Plate 9, already referred to.

The Minor Planets.—If the orbits of the six principal planets known previous to the discovery of Uranus be projected on paper, as is partially attempted in Plate 7, it will be found on an attentive examination of their relative magnitudes that a comparatively wider gap exists between the orbits of Mars and Jupiter than between any other two consecutive orbits of the system. This circumstance did not escape the sagacity of Kepler, who conjectured that a planet really existed between Mars and Jupiter which was too small to be visible to the naked eye (this was previous to the invention of the telescope). After the lapse of about two centuries this bold surmise was finally verified. On the very first day of the present century, Piazzi, the Italian astronomer, discovered at Palermo, in Sicily, a small planet, which was found, upon the computation of the elements of its orbit by the celebrated Gauss, to revolve in the region between Mars and Jupiter. The name of Ceres, the titular deity of Sicily, was appropriately bestowed on the new member of the planetary system. In 1802 a second planet revolving in the same region was discovered at Bremen by the German astronomer Olbers, to which the name of Pallas was given. To these two achievements succeeded the discovery of Juno by Harding, at Lilienthal, in 1804, and the discovery of Vesta by Olbers, at Bremen, in 1807.

Discovery of Astræa.—The circumstance of Pallas revolving in the same region as Ceres, and the extreme smallness of the two bodies, suggested to Olbers the idea that they might be the fragments of some larger planet which had been shattered to pieces by some internal convulsion; and he ventured upon the conjecture that other fragments might be found revolving in the same region. This bold surmise received some degree of confirmation from

the subsequent discovery of Juno and Vesta, but for many years afterwards it obtained no additional support from any fresh discoveries. At length, in the year 1845, a fifth planet of the group, Astræa, was discovered by Hencke, a German astronomer, who had devoted the previous fifteen years to a laborious search for new planets in the region between Mars and Jupiter, and whose industry and zeal thus met with its due reward. This was followed in 1847 by the discovery of a sixth planet of the group, Hebe, due also to Hencke. Several zealous observers now devoted themselves with great energy to the object of discovering new members of the group. The result has been, that since the discovery of Astræa in 1845 several new members of the group have been added to the planetary system every year, insomuch that their aggregate number now (December 1868) amounts to 106.

List of Minor Planets.—The following is a list of the minor planets, or asteroids as they are frequently called, inserted in the order of their discovery:—

(1) Ceres.	(23) Thalia.	(44) Nysa.	(65) Cybele.	(86) Semele.
(2) Pallas.	(24) Themis.	(45) Eugenia.	(66) Maia.	(87) Sylvia.
(3) Juno.	(25) Phocæa.	(46) Hestia.	(67) Asia.	(88) Thisbe.
(4) Vesta.	(26) Proserpina.	(47) Aglaia.	(68) Leto.	(89) Julia.
(5) Astræa.	(27) Euterpe.	(48) Dores.	(69) Hesperia.	(90) Antiope.
(6) Hebe.	(28) Bellona.	(49) Pales.	(70) Panopæa.	(91) Ægina.
(7) Iris.	(29) Amphitrite.	(50) Virginia.	(71) Niobe.	(92) Undina.
(8) Flora.	(30) Urania.	(51) Nemausa.	(72) Feronia.	(93) —*
(9) Metis.	(31) Euphrosyne.	(52) Europa.	(73) Clytia.	(94) —
(10) Hygeia.	(32) Pomona.	(53) Calypso.	(74) Galatea.	(95) Arethusa.
(11) Parthenope.	(33) Polyhymnia.	(54) Alexandra.	(75) Eurydice.	(96) Ægle.
(12) Victoria.	(34) Circe.	(55) Pandora.	(76) Freia.	(97) Clotho.
(13) Egeria.	(35) Leucothea.	(56) Melete.	(77) Frigga.	(98) Ianthe.
(14) Irene.	(36) Atalanta.	(57) Mnemosyne.	(78) Diana.	(99) —
(15) Eunomia.	(37) Fides.	(58) Concordia.	(79) Eurynome.	(100) Hecate.
(16) Psyche.	(38) Leda.	(59) Olympia.	(80) Sappho.	(101) Helena.
(17) Thetis.	(39) Lætitia.	(60) Echo.	(81) Terpsichore.	(102) —
(18) Melpomene.	(40) Harmonia.	(61) Danae.	(82) Alcmene.	(103) —
(19) Fortuna.	(41) Daphne.	(62) Erato.	(83) Beatrix.	(104) —
(20) Massilia.	(42) Isis.	(63) Ausonia.	(84) Clio.	(105) —
(21) Lutetia.	(43) Ariadne.	(64) Angelina.	(85) Io.	(106) —
(22) Calliope.				

Limiting Mean Distances.—The mean distances of all the planets in the foregoing group oscillate between 318 millions of miles, the mean distance of Sylvia, the eighty-seventh of the group, and 200 millions of miles, the mean distance of Flora, the eighth of the group. Consequently, the mean distances are all included within a zone the breadth of which is 118 millions of miles, and the limits of which are represented by the numbers just given.

Principal Discoverers.—The discovery of the minor planets is due to the energy and zeal of a small number of astronomers of different countries. In the list of those who have devoted themselves to this object, the names of Luther, Goldschmidt, Hind, De Gasparis, and Watson, are especially distinguished. Luther has discovered sixteen planets; Goldschmidt, fourteen; Hind, ten; De Gasparis, nine; and Watson, nine.

* Planets 93, 94, 99, 102, 103, 104, 105, 106, have not yet been named.

Diameters.—The minor planets exhibit no appreciable discs. In general they are less bright than stars of the ninth magnitude. It has consequently been impossible, except in one or two instances, to determine their absolute magnitudes by the measurement of their apparent diameters, as in the case of the larger planets of the system. Attempts have accordingly been made to ascertain their magnitudes by a photometric process, founded on the quantity of solar light which they severally reflect. In this way Professor Bruhns, a German astronomer, has arrived at the following results :—

Asteroid,	Diameter in Miles.	Asteroid,	Diameter in Miles.
Ceres,	227	Lutetia,	40
Pallas,	172	Calliope,	96
Juno,	112	Thalia,	42
Vesta,	228	Themis,	36
Astræa,	61	Phocea	31
Hebe,	100	Proserpine	47
Iris,	96	Euterpe,	39
Flora,	60	Bellona,	59
Metis,	76	Amphitrite,	83
Hygeia,	111	Orania,	51
Parthenope,	62	Euphrosyne,	50
Victoria,	41	Pomona,	35
Egeria,	73	Polyhymnia,	38
Irene,	68	Circe,	29
Eunomia,	12	Leucothea,	25
Psyche,	93	Atalanta,	20
Thetis,	52	Fides,	41
Melpomene,	54	Leda,	29
Fortuna,	61	Lætitia,	87
Massilia,	68		

Aggregate Mass.—What may be the aggregate number of the asteroids revolving between Mars and Jupiter it is impossible even to conjecture upon any reasonable grounds. That their aggregate mass is at any rate small, has been established beyond doubt by the result of recent researches in physical astronomy. Le Verrier has shown that if the aggregate mass of the asteroids amounted to one-fourth of the earth's mass, their attractive forces could not fail to disturb sensibly the motion of Mars. Since observation affords no indication of the existence of such a disturbance, we must conclude that the aggregate mass of the asteroids falls below the limit just stated.

Jupiter.—This is the greatest of all the planets, its diameter being no less than 84,000 miles. Viewed in the telescope, it presents a round disc like the full moon. Its apparent diameter varies between 30" and 46". When examined with telescopes of sufficient power, its surface appears diversified with belts of a dusky colour, extending in parallel directions across the more central parts of the disc. Sometimes, but very rarely, the belts are seen extending over the whole disc, always, however, in the same parallel directions. In general three belts only are distinctly visible. From these are seen to issue several short branches, and occasionally dark spots, which are perceived to retain for some time the same characteristic aspect. By an attentive observation of these spots it has been discovered that the planet, like the Earth, revolves upon a fixed axis. The time of a complete rotation of the planet has been determined to be 9h. 55m. 21.3s.

Spheroidal Figure.—From the rapid rotation of Jupiter it might be reasonably surmised that the figure of the planet would be flattened at the poles, as in the case of the earth. Indeed, when we take into account the circumstance of the planet revolving much more rapidly than the earth, we might infer that it would deviate considerably more from a sphere than the earth does. This conclusion is most satisfactorily borne out by the results of observation. It has been

found by actual measurement that the ellipticity amounts to one-fifteenth—in other words, that the equatorial exceeds the polar axis by one-fifteenth of the whole value of the former. It is worthy of remark that this is the precise result which is derivable from abstract researches based upon the principles of the theory of gravitation.

Physical Constitution of the Planet.—There is reason for believing that Jupiter is encompassed by an atmosphere of great extent. The variable aspect of its surface, the parallelism of the belts to the equator, and the circumstance of the more prominent belts being invariably seen in the equatorial regions of the planet, all tend to support this opinion. Cassini, in the seventeenth century, discovered that the dusky spots seen near the equator of the planet revolved with a greater velocity than those which were more distant from it. This interesting fact has been verified in more recent times by the observations of Schroeter. Sir William Herschel, who devoted much attention to the physical constitution of Jupiter, supposed the spots to be large accumulations of clouds in the atmosphere of the planet, which were impelled by strong winds in the direction of the planet's rotation. He generally found that a spot returned in virtue of the planet's rotation to the same position on its surface in gradually diminishing intervals of time, subsequently to its first appearance. This he attributed to the circumstance that some time elapsed before the spot acquired the velocity of the current of air by which it was impelled. Indeed, it is difficult to resist the conclusion that the belts of the planet which are seen to fluctuate so rapidly and so extensively have a strong analogy to the trade-winds which blow upon the earth, originating in each case in the rotation of the planet combined with the existence of an atmosphere which is liable to extensive fluctuations from the agency of the sun's heat.

Satellites of Jupiter.—Jupiter is attended by four satellites revolving round it in orbits of different magnitudes, in the same manner as the moon revolves round the earth. These satellites, although bodies of considerable magnitude, are not visible to the naked eye, but they may be seen in telescopes of the most ordinary power. Their original discovery by Galileo, which was one of the earliest results of the application of the telescope to the purposes of astronomical observation by the celebrated Italian philosopher, constituted an invincible argument in favour of the Copernican system of the universe, which had not yet been generally established in men's minds as the true exponent of the phenomena of the heavens. The satellites are usually distinguished by the order of their respective distances from the primary. Thus the satellite nearest to the planet is called the *first* satellite. The next to this is the second satellite, and then, proceeding outwards, we have the third and fourth satellites in succession.

The following are the results at which astronomers have arrived with respect to the distances of the satellites from the centre of the primary, their times of revolution and absolute diameters, the equatorial radius of the planet being assumed as the unit of distance.

	Distance.	Time of Sidereal Revolution. D.	H.	Min.	Diameter. Miles.
1st Satellite, ...	6.05	1	18	28	2349
2d ,, ...	9.62	3	13	14	2107
3d ,, ...	15.35	7	34	3	3442
4th ,, ...	26.00	16	16	32	2945

Eclipses of the Satellites.—The satellites, in the course of their respective revolutions, pass very frequently into the shadow of the planet, and thereby undergo eclipses. As these phenomena occur at the same physical instant over the whole world, they were at one time extensively used for determining the difference of longitude of places on the earth's surface. Even in the present day the eclipses of the satellites are frequently used by travellers for ascertaining roughly the longitudes of places in distant countries; but for the more refined

objects of geodesy and astronomy, the method based upon such phenomena has been supplanted by others leading to results of greater accuracy.

Occultations and Transits of the Satellites.—The satellites, while revolving round the central body, sometimes pass directly between the earth and the planet, on which occasions they are seen like a round dark speck transiting the disc of the planet. Frequently also there is to be seen at the same time upon the body of the planet the shadow which the satellite casts by its interception of the sun's light. The satellite precedes or follows its shadow according to the position of the planet relatively to the earth and the sun. Previous to the time of opposition—that is, the time when the earth and planet, by their respective movements, come into the same straight line with the sun—the shadow precedes the satellite. After opposition, the satellite, on the other hand, precedes the shadow. In Plate 9 there are two views of Jupiter. The figure on the left exhibits the planet accompanied by its four satellites, three on one side of the disc and the remaining satellite on the opposite side. The satellites, when viewed in a telescope, generally appear ranged in a straight line as in the figure, only that, of course, they form all sorts of configurations as regards mutual distance by their relative movements. In the figure on the right may be seen upon one of the belts a satellite transiting the disc of the planet preceded by its shadow, represented by a round black spot.

Discovery of the Gradual Propagation of Light.—The grand discovery of the gradual propagation of light by the Danish astronomer Roemer towards the close of the seventeenth century resulted from a careful discussion of recorded observations of the eclipses of Jupiter's satellites. Roemer found that when the earth was in the part of its orbit which is nearest the planet the eclipses of the satellites occurred *earlier* than they ought to do, according to the theory of the movements of the satellites founded upon the totality of the eclipses observed in different parts of the orbit. On the other hand, when the earth was in the part of its orbit which is most remote from the planet, the eclipses occurred somewhat *later* than they ought to do, according to the established theory of the movements of the satellites. He was thus led to discover the true explanation of the anomaly in the fact that light is not propagated instantaneously, but occupies a certain interval of time in its passage from the source of light to a point in space situated at a definite distance beyond. According to the most recent researches of astronomers, light travels through space at the rate of 186,000 miles in a second of time!

Saturn.—This is, after Jupiter, the largest of all the planets. Its diameter is 76,000 miles. Its figure deviates from a sphere still more considerably than in the case of Jupiter. According to the micrometric measurements of Mr Main, the Director of the Radcliffe Observatory, Oxford, the polar is to the equatorial axis as 175 to 156—in other words, the ellipticity amounts to $\frac{1}{9.33}$. It might be presumed that such a considerable flattening of the planet at the poles must be the result of a rapid rotatory motion. Observation confirms this surmise. It has been found that the planet revolves on a fixed axis in 10 hours 16 minutes.

Aspect and Physical Constitution.—Saturn, viewed with the naked eye at the time of opposition, resembles a star of the first magnitude. Its apparent diameter corresponding to the mean distance from the sun amounts to 18″. Viewed in the telescope, the surface of this planet appears diversified with faint belts extending across the disc in parallel directions, as in the case of Jupiter. Like the belts of Jupiter also, they coincide in direction with the equator of the planet, embracing especially the equatorial regions. These phenomena in all probability indicate the existence of an extensive atmosphere encompassing the planet, and preventing us from seeing its real surface.

The Ring.—Saturn is encompassed by a singular appendage, consisting of a broad flat ring of extreme thinness, separated all round from the body of the planet. The plane of the ring is inclined to the ecliptic at an angle of about 28° 11′. It results from this circumstance that the

ring never turns its full face towards us, in which case it would present a perfectly circular form. On the contrary, it always exhibits the figure of an ellipse, the excentricity of which varies according to the position of the planet in its orbit. The plane of the ring cuts the ecliptic in two opposite points of the celestial sphere, which, according to the usual nomenclature of astronomy, are termed the *nodes* of the ring. When the planet, in the course of its revolution round the sun, passes through either of those nodes, the plane of the ring must necessarily pass through the sun, and if the earth should happen to be in opposition at the same time, or nearly so, the ring being turned edgeways to the observer, and being excessively thin, will be either altogether invisible, or will present merely the aspect of two radial bars extending from the opposite limbs of the planet. Henceforward the plane of the ring will gradually turn towards the earth, and the ring will open out, presenting at first the appearance of an excessively elongated ellipse, until the planet arrives at a distance of 90° from the node, when the opening of the ring is the greatest possible. The minor axis of the ring is now almost exactly equal to half the major axis. As the planet revolves from this position, the ring gradually closes, and finally assumes its original aspect upon the passage of the planet through the succeeding node of the ring. It thus appears that the ring passes through the cycle of its phases in the course of half a revolution of the planet round the sun. Since the ring encompasses the planet on all sides, it is seen to cast a shadow on the planet at the part where it is directly interposed between the planet and the sun, while again the opposite part of the ring receives the shadow of the planet which is in its turn interposed between the ring and the sun. These interesting phenomena prove not only that the planet is an opaque body, but that the ring also is opaque, both the planet and its appendage shining only by the reflected light of the sun.

The Ring discovered to be Double.—Galileo first recognised the existence of an appendage to the planet Saturn, but he was unable to make out its real nature. This was reserved for the celebrated Dutch astronomer Huyghens, who discovered, about the middle of the seventeenth century, that the planet is surrounded by a ring. Shortly afterwards, an English observer, Ball, discovered that the ring is in reality double, being divided everywhere into two parts by a narrow black streak. Considered with respect to the body of the planet, the two subdivisions have been severally denominated the exterior and the interior ring.

Discovery of a Third Ring.—In 1850 a third ring, existing between the double ring and the planet, was discovered in America by Bond, and nearly about the same time in England by Dawes. It is much fainter than either of the previously discovered rings, and has in consequence received the appellation of the *obscure or dark ring.*

The following are the dimensions of the exterior and interior bright rings, and of the dark ring:

	Miles.
Exterior diameter of exterior ring,	169,110
Interior diameter,	148,830
Exterior diameter of interior ring,	145,400
Interior diameter,	112,470
Breadth of exterior ring,	10,140
Breadth of division between the rings,	1,715
Breadth of the interior ring,	16,465
Breadth of dark ring,	7,320
Distance between dark ring and planet,	10,980
Equatorial diameter of planet,	75,917

According to Sir William Herschel, the rings have a rotatory motion round the planet, effecting a complete rotation in 10 hours, 32 minutes, 15 seconds. The stability of the rings has been ascribed to this movement.

The faint ring can be seen only in telescopes of great power, and even then only under very favourable circumstances. It is of transparent structure, the planet having been seen through its substance by several eminent observers.

A view of the planet and its rings from an original drawing by Mr De La Rue is given in Plate 9.

Satellites of Saturn.—Saturn is surrounded by eight satellites, revolving round it in orbits of different magnitudes. The following table exhibits the distances of the satellites from the centre of the primary, and the times of their several revolutions. The distances are given in terms of the semi-diameter of the planet assumed as the unit of measure. The satellites are set down in the order of their distance from the primary, commencing with the innermost.

Order of Distance from Primary.	Name of Satellite.	Distance from Centre of Planet.	Time of Revolution.			
			Days.	Hours.	Min.	Sec.
1	Mimas.	3.3607	0	22	37	23
2	Enceladus.	4.3125	1	8	53	7
3	Tethys.	5.3396	1	21	18	26
4	Dione.	6.8398	2	17	41	9
5	Rhea.	9.5528	4	12	25	11
6	Titan.	22.1450	15	22	41	25
7	Hyperion.	28.?	21	7	7	41
8	Japhet.	64.3590	79	7	53	40

The first two of the satellites in the foregoing list were discovered by Sir William Herschel in 1789; the third and fourth were discovered by Cassini in 1684; the fifth was discovered by Cassini in 1672; the sixth was discovered by Huyghens in 1655; the seventh was discovered by Bond and Lassell in 1848; and the eighth was discovered by Cassini in 1671. It will thus be seen that the order of distance from the primary of the satellites by no means corresponds to the order of their discovery.

All the satellites, with the exception of the eighth, revolve in the plane of the ring, which is coincident with the equator of the planet. The orbit of the eighth satellite is inclined to the equator of the planet at an angle of about 12°. The sixth satellite, Titan, is by far the most considerable body of the system. It is probably not inferior in magnitude to the planet Mars. The two innermost satellites have been seen only in telescopes of superior power, and under the most favourable atmospheric circumstances.

Uranus.—The planet Uranus, which comes next in the order of distance from the sun, was discovered by Sir William Herschel in 1781. Its diameter amounts to 34,000 miles. By reason of its great distance its apparent diameter measures only 4". This planet is attended by four satellites. Their names, distances from the primary, and times of revolution, are exhibited in the following table:—

Order of Distance from Primary.	Name of Satellite.	Distance from Centre of Planet.	Time of Revolution.			
			Days.	Hours.	Minutes.	Seconds.
1	Ariel.	7.44	2	12	29	21
2	Umbriel.	10.37	4	3	28	8
3	Titania.	17.01	8	16	56	25
4	Oberon.	22.75	13	11	6	55

The first and third of these satellites were discovered by Sir William Herschel; the second and fourth by Lassell.

A remarkable circumstance exists in connexion with the movements of the satellites of Uranus. Instead of revolving in the order of the signs, or from west to east, as do all the planets, and also the satellites of the Earth, Jupiter, and Saturn, they revolve in the opposite direction. In other words, their motion is *retrograde*.

Neptune.—The planet Neptune was discovered in the year 1846 by means of the perturbations which it produces in the movement of the neighbouring planet Uranus. The theoretical discovery of the planet was the result of independent researches executed at the same time by Mr Adams in England and M. Le Verrier in France. Its actual discovery by Dr Galle at Berlin was effected by the indications of Le Verrier. The diameter of this planet is about 40,000 miles. It is accompanied by one satellite, the motion of which, as in the case of the satellites of Uranus, is retrograde.

We shall conclude this chapter with the following synopsis of the masses of the principal bodies of the planetary system, the mass of the earth being represented by 100 :—

Mercury,	10
Venus,	79
The Earth,	100
Mars,	12
Jupiter,	30,422
Saturn,	9,104
Uranus,	1,518
Neptune,	2,207
The Sun,	31,880,000

A view of the relative magnitude of the planets is exhibited in Plate 9.

CHAPTER XV.

Comets—Opinion of the Ancients respecting them—Tycho Brahe proves that they revolve in the Celestial Regions—Newton demonstrates that their movements are subject to the law of Universal Attraction—Discovery of the Periodicity of Halley's Comet—Notice of several other Comets—Concluding Remarks.

Comets are a class of bodies of unusual aspect, which appear from time to time in the heavens. They generally consist of a hazy luminous substance, termed the head, accompanied by a long train of light, which has been distinguished by the appellation of the tail. In the centre of the head is frequently seen a bright starlike point called the nucleus.

When a comet is first seen, it usually presents merely the aspect of a faint nebulous substance without any trace of a tail. Every night, however, it becomes more conspicuous, and finally is seen to throw out a tail in the direction opposite to that in which the sun is situated. After continuing visible for a few nights or weeks, in some rare instance months, it ultimately vanishes from observation.

The tail is by no means an essential accompaniment of comets. Many bodies of this class, especially such as are visible only in telescopes, exhibit no trace of a tail during the whole time of their apparition. A view of a telescopic comet is given in Plate 10.

It has been already stated that the tail of a comet extends into space in the direction opposite to that in which the sun is situated for the time being. This interesting fact was first

remarked in Europe by Peter Apian, an astronomer of the sixteenth century, who found, by attentive observation, that it was true for the comet of 1531 and four other comets which appeared between 1531 and 1539. It has since been established as a general law affecting all comets. It appears, indeed, from recent researches in Chinese literature, that the same fact had been already recognised by the astronomers of China, reference being distinctly made to it in an account of a comet which appeared in the year 837 A.D.

The ancient philosophers supposed that comets are merely substances of a transient nature, generated in the upper regions of the atmosphere; they consequently did not include them in the category of bodies which formed the subject of astronomical research. It was reserved for Tycho Brahé to prove that comets are bodies revolving in the celestial regions far beyond the limits of the earth's atmosphere. This he was enabled to do by means of the observations of a splendid comet which appeared in the year 1577, and which he demonstrated to revolve in space at a distance from the earth exceeding the extreme limits of the moon's orbit.

Unlike the planets, which all revolve in the same direction, comets revolve some in one direction—the same, for instance, as that which characterises the movements of the planets—others again in the opposite direction. In the former case the motion of the comet is said to be *direct;* in the latter it is said to be *retrograde.*

Newton's Researches.—Newton proved that the movements of comets are governed by the attraction of the sun. He demonstrated that the orbit of the great comet of 1680 was sensibly a parabola in the focus of which the sun was situated, and that the movement of the comet in its orbit was regulated in accordance with Kepler's second law. The immortal author of the 'Principia' achieved another step of the highest importance in cometary astronomy. He gave the first solution of the great problem for determining the elements of a comet's orbit from a definite number of its observed positions in the heavens.

The parabola is not a closed curve, like the circle or the ellipse. It consists of two diverging branches extending indefinitely into space. It is plain, therefore, that if a body revolve in a parabola, it can never return to the position which it has once quitted. It is to be remarked, however, that if a body revolve in a very excentric ellipse, its path towards the perihelion will not differ sensibly from a parabola. Newton, who was well aware of this fact, was of opinion that comets in reality revolve in very excentric ellipses, although their orbits towards the perihelion might be assumed to be sensibly parabolic. By proceeding upon this latter assumption, the elements of the comet's orbit might be determined by the method which Newton had given, with the exception of the time of revolution, which depended on the major axis of the ellipse, and which the parabolic hypothesis was of course incapable of furnishing. Newton, however, perceived that if a comet revolve in an elliptic orbit, its elements (independently of the time of revolution) must be the same for different apparitions. He suggested, therefore, that the time of revolution, and, consequently, the major axis of the ellipse in which the comet revolved, might be ascertained by an intercomparison of the computed elements of cometic orbits. If any two apparitions of comets presented the same elements, the interval between the apparitions would indicate the time of revolution of the comet.

Halley's Researches.—Here, then, was a prize offered to astronomers. There existed in the records of past ages of modern Europe a great number of apparitions of comets, accompanied in many instances with details of their observed positions. If from such materials the parabolic elements of the orbit were in each instance computed, what might not the intercomparison of the results reveal! No doubt the observations in many instances were rude; still, if treated with sagacity and sound discrimination, they might lead to results of the highest importance. Fortunately England possessed at this time an astronomer who enthusiastically adopted Newton's

views, and who was endowed with intellectual abilities adequate to the solution of the arduous problem which they proposed. This was the celebrated Edmund Halley. With incredible labour he computed the orbits of twenty-four recorded comets, and the question now was, Did the resulting orbits in any two or more instances bear so close a resemblance as to indicate beyond doubt that they referred to the same comet? Upon comparing the elements of a comet observed by Flamsteed and others in 1682 with those of a comet observed by Kepler and Longomontanus in 1607, he discovered a very strong resemblance. It seemed to him, therefore, very probable that the two comets were not two really different bodies, but were merely two distinct apparitions of the same comet which revolved round the sun in a period of about seventy-five years. This conjecture was confirmed beyond all doubt in his mind upon ascertaining that the elements of a comet which appeared in 1531 very closely resembled those of the comets of 1607 and 1682. He therefore finally concluded that the three apparitions referred to the same comet, which revolved in an elliptic orbit in a period of about seventy-five or seventy-six years, and he boldly predicted that it would again return to the perihelion towards the close of 1758 or in the beginning of 1759.

Return of Halley's Comet to the Perihelion.—As the time fixed by Halley for the return of the comet drew nigh, the subject excited an intense interest in the astronomical world. Clairaut, a distinguished French astronomer, undertook the difficult task of calculating the exact time of the comet's passage of the perihelion, taking into account the disturbing influence which the great planets Jupiter and Saturn would exercise on its movements. He found as the result of his calculations that Jupiter would retard the comet 508 days and Saturn 100 days; and he finally concluded that the passage of perihelion of the comet would occur on the 13th of April 1759. He remarked that in consequence of the uncertainty which existed respecting the exact masses of the disturbing planets, and certain minute quantities which he omitted in his calculations, the time for the passage of the perihelion, as thus announced by him, might be erroneous to the extent of a month. The comet was actually discovered by a Saxon peasant, Palitzch, on the 25th of December 1758. It was found that the passage of the perihelion took place on the 12th of March 1759, consequently within the limits of the time assigned by Clairaut. This famous comet, which has been justly named after the discoverer of its periodicity, returned again to the perihelion in the month of November 1835. On that occasion also its movements were subjected beforehand to a most rigorous computation by several distinguished astronomers, and the results were subsequently found to present a most satisfactory accordance with those derived from actual observation. The passage of the perihelion took place on the morning of November 16, 1835.

It was ascertained by Pingré, a French astronomer of the last century, that this famous comet is identical with a great comet which appeared in 1456. M. Laugier, another French astronomer, has recently found that a comet observed in China in the year 1378 was no other than an apparition of Halley's comet. Indeed, there are good grounds for believing that this comet is identical with several other apparitions of comets recorded either in Europe or China, and extending as far back as the beginning of the Christian era.

A representation of the orbit of Halley's comet is given in Plate 10. The results relative to the least and greatest distance of the comet from the sun are:—

Perihelion distance, ...	54 millions of miles.
Aphelion distance, ...	3258 ,,

The following are the results of the calculations (founded on the observed positions) which have been executed with reference to the successive times of revolution, extending

from the year 1378, the date of the earliest authentic apparition of the comet, down to 1835:—

	Period. Years.
From 1378 to 1456,	76.6
,, 1456 to 1531,	75.2
,, 1531 to 1607,	76.1
,, 1607 to 1682,	74.9
,, 1682 to 1759,	76 5
,, 1759 to 1835,	76.7

The differences observable in these periods is due to the effects of planetary perturbation, which will necessarily vary from one revolution to another according to the position which the comet may occupy relatively to the disturbing planets.

In addition to Halley's comet, several other comets have been ascertained by the researches of astronomers to revolve in elliptic orbits round the sun. Hitherto, however, the great majority of cometic orbits have been found to be sensibly parabolic.

We proceed to notice briefly a few other comets which have been observed in modern times, and which have been remarkable either for the splendour of their apparition or for some point of scientific interest connected with them.

Comet of 1680.—It has been already stated that the great comet of 1680 is memorable for having furnished Newton with the materials which enabled him to demonstrate that comets are mainly governed in their movements by the attractive force of the sun. This comet is also remarkable for having approached nearer the sun than any other comet recorded in history, with the exception of the great comet of 1843. The perihelion distance of its orbit amounted, in fact, to only 550,000 miles. It therefore approached within 125,000 miles of the sun's surface. Newton calculated that the heat which the comet was subjected to at the time of the passage of the perihelion must have been two thousand times greater than that of red-hot iron.

Lexell's Comet.—In 1770 a comet was discovered by the French astronomer Messier, which was destined to lead to results of a highly interesting nature. Upon calculating the elements of its orbit, the astronomer Lexell found that the theory of a parabola would not satisfy the observations, and that in order to effect this object it was necessary to suppose that the comet revolved in an ellipse, the time of a complete revolution being about 5½ years. He accordingly announced that the comet would again return to the perihelion in 1776. The comet, however, has not been seen since. It was found, indeed, that the non-apparition of the comet in 1776 arose from the circumstance of its having passed the perihelion in the daytime, but there still remained for solution the much larger question, How was it that a comet revolving in so short a period round the sun had not been visible previous to 1770, nor has been seen at any subsequent passage of the perihelion? Lexell accounted for this anomalous circumstance by remarking that previous to 1767 the comet was revolving in an orbit which rendered the comet *invisible* to an observer on the earth's surface; but having in that year approached very near to Jupiter, it was thrown by the powerful disturbing attraction of the planet into a new orbit, and rendered *visible;* and that having again approached very near to the some planet in 1779, it was a second time thrown into a new orbit and rendered *invisible.* The researches of the eminent French astronomer Le Verrier have proved beyond all doubt that this is the true explanation of the anomaly, being in perfect accordance with the principles of the theory of gravitation.

Comet of 1811.—In 1811 there appeared one of the most splendid comets of which history makes mention. It was first seen on the 26th of March, but it did not present a conspicuous

aspect in the heavens until the following autumn. The passage of the perihelion took place on the 12th of September. For a few weeks previous, and several months afterwards, it exhibited a grand appearance, and being a circumpolar object, was visible during the long nights of winter at every hour of the night when the sky was clear. The tail, when apparently longest, measured 25°. Its absolute length amounted to 100 millions of miles. Astronomers have assigned to this comet an orbit, the period of which is 3065 years. This result has reference to the ellipse which the comet was describing at the time of its passage of the perihelion in 1811. Its subsequent movements have been, and will continue to be, materially influenced by planetary perturbation. A view of this famous comet is given in Plate 10.

Encke's Comet.—In 1818 a comet was discovered at Marseilles by a French observer, Pons, which was shortly afterwards found by Encke to revolve in an elliptic orbit with a period of somewhat more than three years. Encke further showed that the comet was identical with comets which appeared in the years 1786, 1795, and 1805. This comet has regularly returned to perihelion since the discovery of its periodicity. Its time of revolution was, however, soon remarked by Encke to be affected by a strange anomaly. After taking into account the effects of planetary disturbance, he found that the time of revolution was gradually shortening, a result contrary to the established principles of the theory of gravitation. He was accordingly led to suspect that the movements of the comet might be influenced by the action of a resisting medium of extreme tenuity pervading space, and he found that a theory, framed in accordance with this idea, afforded a satisfactory explanation of the observed irregularity in the time of revolution. The following results, which Encke obtained by a discussion of the observations made on the occasion of each successive passage of the perihelion, establish beyond all doubt the existence of a gradual shortening of the time of revolution of the comet:—

Year of Passage of the Perihelion.	Time of Revolution in Days.	Year of Passage of the Perihelion.	Time of Revolution in Days.
1819, . . .	1211.78	1842, . . .	1210.98
1822, . . .	1211.66	1845, . . .	1210.88
1825, . . .	1211.55	1848, . . .	1210.77
1829, . . .	1211.44	1852, . . .	1210.65
1832, . . .	1211.32	1855, . . .	1210.55
1835, . . .	1211.22	1858, . . .	1210.44
1838, . . .	1211.11		

It would appear from these numbers that the acceleration of each successive passage of the perihelion amounts to 1-10th of a day, or somewhat more than two hours.

The observations of the comet made in the years 1786, 1795, and 1805 afforded to Encke indications of a similar shortening of the time of revolution of the comet.

Results of a similar nature have been derived from an examination of the movements of Faye's comet, which revolves in an elliptic orbit, the period being about seven years and a half. This comet, however, was only discovered in 1843, so that a sufficient time has hardly yet elapsed for employing satisfactorily its observed movements in a question so delicate as that of the existence of a resisting medium. In the mean time no indications of the existence of such a medium have been furnished by the movements of any other celestial body. The question must, therefore, be regarded as not having yet received a definitive solution.

Biela's Comet.—This comet was discovered in 1826 by Biela, an Austrian officer, hence

its name. It was soon found to revolve in an elliptic orbit, the period being about 6¾ years. The orbit of this comet is remarkable for intersecting the plane of the ecliptic at a point excessively near to the earth's orbit. The approach indeed is so close, that if the earth and comet should happen to be travelling at the same time in the parts where their respective orbits approach nearest to each other there might arise a collision of the two bodies. Olbers, the German astronomer, remarked with reference to the return of the comet to perihelion in 1832, that the comet would pass through the plane of the ecliptic at a point which was distant only about 18,000 miles from the earth's orbit. He further ascertained by actual measurement that the radius of the nebulosity of the comet amounted to about 20,000 miles. It was possible, therefore, that while the comet was passing through the node of its orbit the earth might be so situated as to be involved in the nebulosity of the comet. When the result of Olbers's calculations was publicly announced, a feeling of alarm was very generally felt, especially on the Continent, lest the two bodies should come into collision. Further researches of astronomers showed, however, that no real ground existed for such alarm. It appeared, in fact, that while the comet would pass through the plane of the ecliptic on the 29th of October, the earth would not arrive in the same position until the 30th of November. The distance between the two bodies could not, therefore, have been at any time less than 40 or 50 millions of miles.

A singular phenomenon was observed on the occasion of the return of this comet to perihelion in 1846. About six weeks previous to the passage of the perihelion the comet was seen to acquire an elongated shape, which resulted shortly afterwards in its breaking up into two distinct parts. The two fragments continued to pursue their way through space, each revolving in its own ellipse, the distance between them remaining constantly equal to about 150,000 miles during the whole period of their visibility. Upon the return of the comet to perihelion in 1852 it was again found to be double, but the two parts were very faint; their mutual distance was also much greater than in 1846. Circumstances have not been favourable for the observation of the comet on the occasions of either of the two subsequent passages of the perihelion.

The Great Comet of 1843.—This is one of the most splendid comets of which history makes mention. It first appeared in the southern hemisphere, when it was most conspicuous as a *sight object*. On the 28th of February it was perceived with the naked eye in the immediate vicinity of the sun by persons in various parts of the world. The tail, when it acquired its greatest development, measured 150 millions of miles in length. This comet is remarkable for having approached nearer the sun than any other comet recorded in history. At the time of the passage of the perihelion the distance of the comet from the sun's surface did not amount to more than 49,000 miles!

Great Comet of 1858.—This is, after the comets of 1811 and 1843, the greatest comet of the present century. Indeed, if we consider only the northern hemisphere of the earth, the comet of 1811 alone can vie with it in splendour. It was first seen by Donati at the Florence Observatory on the 2d June, but it did not become visible to the naked eye until the end of the following August. During the month which elapsed between the middle of September and the middle of October the comet presented a magnificent aspect; and, having a northern declination, was especially favourable for observation in the northern hemisphere. The passage of the perihelion took place on the morning of the 30th September. A few days afterwards the comet attained its greatest splendour. The tail measured 40°. Its absolute length amounted to about 40 millions of miles. Several astronomers have computed the orbit of this

famous comet. The following numerical results have been derived from the elements assigned by Professor Bruhns, a German astronomer:—

Major axis, or longest diameter of the orbit,	29,881 millions of miles.
Minor axis, or shortest diameter,	2,508 ,,
Perihelion distance,	52 ,,
Aphelion distance,	29,829 ,,
Velocity at the perihelion,	122,090 miles in an hour.
Velocity at the aphelion,	213 ,,
Period,	2101.63 years.

Great Comet of 1861.—This must also be regarded as one of the most magnificent comets of modern times. It was first seen on the evening of June 30. The head was brighter than a star of the first magnitude. The tail, when it attained its greatest length, measured 70°, even when viewed in the strong twilight of July. The comet soon ceased to be visible to the naked eye; but it continued for several months to be observable in the telescopes of astronomers.

We shall conclude this chapter with one or two general remarks upon comets.

The nebulosity which envelops the heads of comets appears to be in every instance composed of a substance of extreme tenuity. The smallest stars may be seen through it without undergoing any appreciable diminution of lustre. This remark is even still more applicable to the matter constituting the tail of a comet. On the 5th of October 1858 the tail of the great comet of that year passed over the star Arcturus; but although almost the densest part of it was interposed between the star and the earth, the star did not exhibit the slightest diminution of brightness.

A few comets have exhibited such intense lustre as to be visible to the naked eye in full daylight. Such was the case with respect to the comets of 1744 and 1843, without referring to some others of earlier date. It has been already stated that the comet of 1843 was seen, in full sunshine, in the immediate vicinity of the sun. The first comet of 1847 was also seen by Mr Hind, with the aid of a telescope, at a distance not exceeding 2° from the sun's limb. A view of the appearance presented by the comet on that occasion is given in Plate 10.

The tails of comets are generally formed of two streams of light diverging from the head, leaving a dark space between. This will be seen by referring to the views of the comets of 1807, 1811, 1858, and 1861, exhibited in Plate 10.

Physical changes of a remarkable nature have been observed to take place in several great comets as they are approaching towards the sun. Streams or jets of luminous matter are seen issuing from the head and curving backwards as if impelled by some very intense force towards the tail, or in the direction opposite to that in which the comet is travelling. The views of the heads of the comets of 1858 and 1861, exhibited in Plate 10 (left side), are intended to illustrate these mysterious processes.

We have already referred to the extreme tenuity of the substance of which comets appear to be composed. We might infer from this circumstance that the masses of comets are inconsiderable. The results of observation are in perfect accordance with this conclusion. No comet has been found to produce a sensible disturbance in the movements of any of the other bodies of the planetary system. A signal illustration of the smallness of a comet's mass was obtained on the occasion of the near approach of Lexell's comet to the planet Jupiter in 1767, and again in 1779, for although the comet on both of those occasions must have passed through the midst of the system of the satellites, it did not produce the slightest perceptible derangement in their movements.

CHAPTER XVI.

Classification of Meteoric Phenomena—Aerolites—Meteoric Iron—Fireballs—Explanations of Aerolites and Fireballs—Theory of Chladni—Shooting Stars—Experiments of Brandes and Benzenberg—Meteoric Shower of August—Its Periodicity established by Quetelet—November Meteors—Cycle of 33¼ years established by Professor Newton—Researches of Professor Adams—Identity of Comets with the Meteoric Showers of August and November—Aggregate Mass of Meteors—Zodiacal Light.

The cosmical origin of meteors having been established beyond doubt by the researches of modern inquirers, the questions relating to the movements and physical constitution of this class of bodies may now be considered as legitimately included within the domain of astronomical science.

Meteoric phenomena may be divided into three classes—*Aerolites* or *Falling Stones*, *Detonating Meteors* or *Fireballs*, and *Shooting Stars*. We proceed to notice briefly each of these classes in succession.

Aerolites.—It is only in the present century that men of science have been finally induced to admit the fact of stones having occasionally fallen to the earth's surface. And yet the annals of past ages contain many records of such occurrences. Thus, if we ascend to the earlier periods of Grecian history we find that at Ægos Potamos, in the year B.C. 465, a huge stone fell to the earth, which was equal to two mill-stones.

If we come down to modern times, the records of the fall of stones to the earth are still more numerous and explicit. One of the earliest of such occurrences, which is based upon authentic evidence, refers to a stone which fell in the district of Ensisheim on the Rhine on the 7th of November 1492. A loud continued noise as of thunder was heard between eleven o'clock and noon, and a stone was seen to fall in a field of wheat, sinking several feet into the earth. By order of the Emperor Maximilian the stone was dug up and removed to the Church of Ensisheim, in which it was suspended with an inscription recording the circumstances of its fall. Its weight was found to be two hundred and sixty pounds.

On the 13th of December 1795 an aerolite fell near the village of Thwing in Yorkshire. The event occurred about three o'clock in the afternoon. A number of distinct explosions, followed by a hissing sound, was heard at the time. In the adjacent villages the noise was supposed to be the reports of guns at sea. The stone as it fell penetrated into twelve inches of soil and six inches of chalk rock. It weighed fifty-six pounds. This stone is now in the British Museum.

On the 26th of April 1803, about one o'olock in the afternoon, an immense number of aerolites fell to the ground near L'Aigle in France. The event was immediately preceded by the apparition of a luminous globe, which was seen throughout a great part of Normandy, traversing the atmosphere with great velocity. At L'Aigle and the surrounding district to the extent of seventy miles several very loud explosions were heard, which were followed by rattling sounds like the firing of musketry and the beating of drums. The air was calm and the sky almost perfectly clear. The noise proceeded from a small cloud which appeared quite motionless during the occurrence of the phenomenon. The vapour of which it was composed appeared to be violently dissipated on the occurrence of the successive explosions. A hissing noise was heard throughout the whole district, and then a vast number of stones were seen to

fall to the earth. The shower extended over a tract of country nine miles long by four miles broad. This remarkable fall of meteorites was verified by the French Institute. With a view to this object they appointed a commission of *savans*, including the distinguished astronomer Biot, who proceeded to the scene of the occurrence and instituted an inquiry into all the facts which had been observed in connexion therewith.

On the 1st of May 1860 there occurred a remarkable fall of meteoric stones in Guernsey County, Ohio, U.S. The event was preceded by several distinct and very loud explosions which lasted about two or three minutes. Two of the stones were seen to descend with a great velocity and a hissing sound burying themselves in the earth. In a space extending about ten miles long by three broad more than thirty meteorites were found to have fallen. The largest weighed 103 pounds.

On the 9th of June 1866 an aerolite fell at Knyahina in Hungary, which weighed upwards of 600 pounds. It was precipitated along with about a thousand smaller stones upon an area ten miles in length by four miles in breadth. The fall of the principal meteorite was preceded by the appearance of a luminous globe and then a violent explosion, leaving in the sky a smoky streak which was visible for about half an hour afterwards.

A multitude of other instances might be cited of the fall of stones to the earth. The reality of such occurrences may therefore be considered as established beyond all doubt.

Composition of Meteorites.—With regard to the materials of which meteorites are composed, it has been found that they differ essentially from terrestrial rocks, inasmuch as they invariably contain a large proportion of metallic iron. Nickel, chromium, tin, copper, and various other substances, have also been found in them, but it is a remarkable fact that no new element that has not been already known to exist has been discovered in their composition.

Meteoric Iron.—Besides those meteorites, the fall of which to the earth has been established as facts of observation, there exist in various parts of the world large metallic masses, the elements of which have been found to be identical with those of meteorites, while on the other hand they have no affinity with the structure of the rocks in the vicinity of which they have been discovered. It is impossible, therefore, to resist the conclusion that they also are in reality meteorites of the same class as those to which we have already alluded, although their descent to the earth has not been established by actual observation. A remarkable meteorite of this class, weighing about 700 pounds, was discovered in the last century on a mountain of slate in Siberia, by Pallas the geologist, and is now deposited in the mineralogical museum of St Petersburg. Bodies discovered in this manner have been found to consist mainly of iron, and the composition of such masses has consequently acquired the denomination of *meteoric iron.*

Fireballs.—Another class of meteoric phenomena to which the name of Fireballs or Detonating meteors has been assigned, consists of luminous globes which are seen to traverse the atmosphere with great apparent velocity and finally burst into fragments, accompanied in many instances by a loud explosion. In 1718 there was seen in the evening all over England an immense luminous meteor, the lustre of which was so intense that the stars ceased to be visible, and the light of the moon, which was nine days old, was almost completely effaced. It was computed to have been travelling at the rate of three hundred miles in a minute, at an elevation of about sixty miles above the earth's surface. A loud explosion was heard at the same time on the opposite coasts of the English Channel.

Another great meteor visited Europe on the 18th of August 1783 traversing the whole space between Shetland and Rome at a distance of 50 miles from the earth's surface, and with a velocity of about 30 miles in a second. In this instance, however, the meteor broke up into

a number of distinct fragments, unaccompanied by any explosive sounds, and finally disappeared.

The following is a recent instance of the apparition of a fireball being accompanied by the fall of a meteorite. On the 8th of September 1868, at half-past two o'clock in the morning, a fireball was seen at Languis, in the department of the Lower Pyrenees, in France. The apparition of the phenomenon was accompanied by violent detonations, and immediately afterwards a meteorite was seen to fall to the earth. The persons who witnessed the occurrence found, upon an examination of the meteorite, that it was broken into a number of distinct fragments. It weighed altogether somewhat more than four pounds.

Physical Theories of Aerolites and Fireballs.—A great number of apparitions of aerolites and fireballs are to be found recorded in the annals of modern science. Various explanations have been advanced with the view of accounting for the origin of these singular phenomena. Halley, in a paper communicated to the Royal Society on the great meteor of 1718, was of opinion that such apparitions arise from the combustion of agglomerations of matter in the upper regions of the atmosphere. But at the time when Halley wrote the fall of aerolites to the earth had not been properly authenticated, and the theory of that astronomer, not to speak of the objections which might be urged against it with reference to the class of phenomena which it was intended especially to explain, is manifestly incapable of accounting for the fall of immense masses of matter to the earth. Other inquirers have attempted to surmount this difficulty by attributing the fall of aerolites to the ejection of fragments of rocks from the moon by volcanic agency; but this hypothesis has been found, upon careful examination, to be incapable of affording a satisfactory account of such apparitions.

Theory of Chladni.—According to Chladni, meteors are cosmical bodies, moving in space in obedience to the sun's attraction. Sometimes they approach so near the earth as to enter the atmosphere, when their rapid motion produces a compression of the air opposed to them, and a consequent evolution of heat which ignites them, and thereby renders them luminous. This explanation accords better with observed facts than any other which has been advanced, and it may be considered as established beyond all doubt by the results of recent researches on *shooting stars*, the third class of meteors which form the subject of this chapter, and to the consideration of which we now proceed.

Shooting Stars.—Any person who surveys the heavens on a clear starry night cannot fail to perceive from time to time the phenomenon of a small speck of light, attended by a luminous train, shooting rapidly down from the heavens, and generally remaining visible only for a second or two. It is to meteors of this class that the apt designation of *shooting stars* has been applied.

It has been found that the number of shooting stars visible on a clear night during any assigned interval of time is not the same throughout the whole night. Their frequency increases from the evening twilight till morning, attaining its minimum about 6 o'clock A.M. at the seasons of the year when the light of the sun does not interfere with their visibility. Observers have also ascertained that the number of shooting stars visible in any given time varies from month to month throughout the whole year. The number visible in an hour about midnight, when the sky is clear and the moon absent, has been found to be 12.8 for the month of August, while again for April the corresponding number is only 4.6, and the numbers for the other months have been ascertained to vary between these two extremes.

Heights of Shooting Stars.—The earliest attempts to determine the heights of shooting stars were made in 1798 by two German philosophers, Brandes and Benzenberg. Having selected a base, measuring about nine English miles in length, Brandes stationed himself at one

extremity of the base, and Benzenberg at the other, and on certain favourable nights they made simultaneous observations of the apparent paths of shooting stars, and of the times of their being visible. In this way they found for a number of shooting stars heights varying from 40 to 140 miles above the earth's surface, and velocities of between 20 and 30 miles in a second. It was clear, from these results, that shooting stars are cosmical bodies traversing space with a velocity, in many instances, exceeding considerably the orbital velocity of the earth.

The results of similar researches, executed on various occasions during the present century, have been found to accord with the conclusions arrived at by Brandes and Benzenberg. In general it may be stated that the average height of meteors, as thus determined, is 70 miles, and that their average velocity is 30 miles in a second. The orbital velocity of the earth is only 19 miles in a second.

The August Meteors.—In 1836 M. Quetelet, Director of the Brussels Observatory, ascertained that there is an annual apparition of shooting stars about the middle of August, or somewhat earlier. They generally appear in considerable numbers every night for a week, commencing with the 6th and ending with the 13th of August, attaining their maximum frequency about the 10th of the month. When their apparent paths in the stellar sphere are traced back, they are all found to emanate apparently from a common point in the heavens. This point is situated in the constellation Perseus, in right ascension 44° and north declination 56°.

Mr A. S. Herschel has recently obtained indications of the presence of sodium in the meteors of this group. A view of the appearance which they exhibited in the spectroscope is given in Plate 13.

The November Meteors.—A still more interesting shower of meteors, the periodicity of which has been established in recent times, is that which appears in the month of November. It has been found on many occasions during the present century that meteors appear in great abundance on the evening of the 12th and 13th of November. Their numbers, however, vary greatly when the apparitions of different years are compared together. In some years they are seen in great abundance; in others, again, their numbers do not exceed those visible on ordinary nights. There are, however, several recorded apparitions of this November shower, separated in each instance by a wide interval of years, which far transcended in splendour any similar displays that have occurred either in November or any other month of the year, and which suggested the idea of a recurring cycle of the shower, distinguished by an extraordinary abundance of meteors.

On the morning of November 12, 1799, there occurred an apparition of meteors which was witnessed by Humboldt in South America, and is thus described by him:—

"From half-past two the most extraordinary luminous meteors were seen towards the east. . . . Thousands of fireballs and shooting stars succeeded each other during four hours. They filled a space in the sky extending from the true east 30° towards the north and south. M. Bonpland relates that from the beginning of the phenomenon there was not a space in the firmament equal in extent to three diameters of the moon that was not filled at every instant with fireballs and shooting stars."

Referring to the same phenomenon, the Count of Marbois, writing at Cayenne, says:—"The northern part of the sky was seen all on fire. Innumerable falling stars traversed the heavens during an hour and a half, and diffused so vivid a light that they might be compared to the blazing sheaves shot out from a firework."

On the 12-13th of November 1832 there occurred an extraordinary apparition of meteors, which was seen in many places on the Continent, and also in England. The late excellent astronomer Mr Dawes thus refers to the phenomenon:—

"Grand as was the display [of 1866], there was not a single meteor which could bear comparison with several which I saw at Ormskirk on the 12th of November 1832; on which occasion, notwithstanding a pretty bright moon, three or four cast a very dark shadow of my observatory towards the side on which the moon was shining. A very thick fog suddenly arose at about 13½ hours;* but several of the country folk, going early with agricultural produce to Liverpool, said that 'though there was a terribly thick fog, yet *it lightened all the way*.' So that probably many brilliant specimens darted across till towards sunrise."

The display of meteors on the 13th of November 1833 appears to have far surpassed in magnificence even the apparition of the previous year. It was very favourably seen in North America, and has been fully described by Professors Twining and Olmstead of the United States. It was on this occasion remarked for the first time that the meteors seemed all to emanate from a point in the constellation Leo, coinciding nearly with the position of the star *γ Leonis*.

Researches of Professor Newton.—In 1864 Professor H. A. Newton, of Yale College, U.S., was led to conclude, from a comparison of a number of recorded apparitions of meteoric showers, that the November meteors recur in extraordinary abundance at epochs of time separated 33¼ years apart. In the annals of the Chinese, the Arabs, and the writers of the Middle Ages, he discovered distinct allusions to the occurrence of meteoric showers, which seemed to be identical with the great November showers of 1799 and 1833. A comparison of the times of apparition indicated that the shower occurred later and later at the close of each successive cycle. He ascertained, in fact, that the intersection of the stream of meteors with the plane of the ecliptic (the passage of the earth through which point of intersection marks the occurrence of the shower) is not fixed, but advances yearly upon the ecliptic in the order of the signs at the rate of 1′ 42″ relatively to the mean equinox. With respect to the orbit, Professor Newton showed that the recorded observations might be satisfied by assuming the meteors to constitute a group of considerable length, and to revolve in an elliptic orbit, which admitted of five suppositions in regard to the time of revolution. In one year the meteoric group might describe either two whole revolutions, *plus* 1-33d, or two whole revolutions, *less* 1-33d; or it might describe one whole revolution, *plus* 1-33d, or one whole revolution, *less* 1-33d: or, finally, it might describe neither more nor less than simply 1-33d of a revolution. In other words, the time of revolution of the meteoric stream would be 180 days, or 185 days, or 354 days, or 376 days; or finally, it might be 33¼ years. On any of these suppositions, however, the phenomenon would be characterised by a recurring cycle, in virtue of which the meteors visited the earth in extraordinary abundance once in every thirty-three or thirty-four years; for a comparison of the recorded apparitions indicated the stream to be of such a length that it may be seen conspicuously in two consecutive years at least, notwithstanding that it flows through the point of its intersection with the earth's orbit at the rate of a million and a half of miles in a day.

Meteoric Display of November 1866.—The views of Professor Newton were generally adopted, and, in accordance with them, it was expected that a great display of meteors would occur in November 1866. The ideas thus entertained respecting the phenomenon received a most striking realisation. On the morning of November 14 there occurred a magnificent apparition of meteors, which was visible in Europe, Western Asia, and Africa. In the British Isles, where the phenomenon was observed with great attention by a large number of persons stationed at different places, the shower was found to have attained its maximum intensity at

* This is the astronomical mode of expressing half-past one o'clock in the morning.

1h. 15 m. At the Royal Observatory, Greenwich, about 8000 meteors were counted between midnight and four o'clock, by Mr Glaisher and his staff of observers. When the shower was at its maximum, the meteors were appearing at the rate of 120 per minute. As in the case of the great apparition of 1833, the meteors all seemed to emanate from a common point in the constellation Leo. The totality of the observations seemed to indicate that the radiant point is situated in longitude 143°, latitude 9° 50′. This position agrees nearly in longitude with the point in the heavens towards which the earth was travelling at the time. Plate 13 contains a representation of the apparent paths of the meteors, as seen on the 13th and 14th of November 1866 at the Royal Observatory, Greenwich. The same Plate also contains a graphic delineation of the number of meteors counted at the Royal Observatory on the same occasion.

Meteoric Displays of 1867 and 1868.—On the morning of November 1867 an equally magnificent display of meteors was witnessed in America. The shower attained its maximum at 4h. 30m. The position of the radiant point agreed with the corresponding result deduced from the observations of the meteoric shower of 1866. The meteors again have quite recently appeared on the morning of November 14, 1868, but they have not been so numerous as in the two preceding years. In this respect the phenomenon rather bore a resemblance to the apparition of 1865. It is clear, indeed, that the densest part of the meteoric stream has already passed.

Researches of Professor Adams.—It has been stated that the intersection of the meteors with the earth's orbit advances annually at the rate of 52″ (relatively to the stars) in the direction of the earth's motion. This is clearly attributable to the disturbing action which the planets exercise upon the meteoric stream; for if it was merely subject to the attractive force of the central body, the sun, its intersection with the earth's orbit—or, in other words, the node of its orbit—would have a fixed position relatively to the stars. Professor Newton perceived that the motion of the node would be different for each of the five hypotheses which are capable of accounting for the recurring apparition of the shower in a cycle of 33¼ years, and he sagaciously remarked that this circumstance would furnish a sure criterion for deciding what was the true form of the orbit in which the meteors revolved, for this would manifestly be the orbit which gave for the motion of the node—when computed by taking into account the effects of planetary perturbation—a result agreeing with the observed motion. Professor Adams, taking up this view of the subject, has computed the motion of the node upon the five different suppositions in respect to the time of revolution, and has found that the period of 33¼ years alone gives a result agreeing with the observed motion. It may be considered, therefore, as established beyond doubt, that the November meteors revolve in an elliptic orbit round the sun, effecting a complete revolution in 33¼ years.

Explanation of the Recurrence of the Shower in two or three Consecutive Years.—In order to account for the apparition of a shower of meteors in two or three consecutive years, we must regard the meteors as forming a stream of definite length revolving in an elliptic orbit. If the meteors were diffused in the same abundance over the entire contour of the ellipse, there would be an apparition of equal magnitude every year, coinciding with the time when the earth, in the course of its annual revolution, arrived in the region where the meteors intersected the terrestrial orbit. This, however, is not consonant to observation. We may therefore infer that the meteors at any assigned instant are mainly confined to an arc of the ellipse of definite length, and are sparingly diffused over the remaining part of the orbit. It has been surmised that they originally formed an agglomerated mass, which has been gradually drawn into its present elongated form by the sun's attraction, and that the process of dislocation will go on until the meteors are finally diffused over the entire contour of the orbit. If

this eventuality should occur, there will then be an apparition of meteors every year of moderate dimensions, while the great shower of 33 or 34 years will have disappeared. This is supposed to be the condition of the August meteors, which appear every year in pretty uniform numbers.

An interesting relationship has been recently discovered to exist between meteors and comets. It has been found that the orbit of the November meteors is identical with that of a comet which appeared in 1866. A similar connexion has been established between the August meteors and a comet which appeared in 1862. A wide field of speculation is here offered up to the researches of scientific inquirers.

In addition to the meteors of August and November, it has been found that at certain seasons of the year other groups of meteors may be seen emanating from definite points in the heavens. By the labours of Mr A. S. Herschel, Mr P. Greg, and other observers of meteors in Europe and America, the radiating points of such meteoric apparitions have been pretty well determined. It would seem, indeed, that there exists a system of elliptical streams of meteors revolving round the sun in various directions, and at all inclinations, with respect to the earth's orbit.

It is probable that aerolites, fireballs, and shooting stars all constitute essentially one class of bodies. Viewed in this light, fireballs may be regarded as a larger species of shooting stars, which in general, like those bodies, are consumed in the earth's atmosphere if they approach sufficiently near the earth. On the other hand, aerolites may be considered as shooting stars, which, in virtue of their magnitude and chemical composition, are enabled to run the gauntlet of the terrestrial atmosphere, and to reach the earth's surface in the form of solid masses.

It is impossible to form any estimate of the number of meteors which may be circulating round the sun. The researches of physical astronomers, however, assure us that the aggregate mass of such bodies must be inconsiderable.

Zodiacal Light.—We shall conclude this chapter by briefly adverting to the zodiacal light, which may be regarded as forming a part of the solar system, although its real nature is involved in profound mystery. It is generally described as a faint lenticular-shaped light, which is usually best seen for a few weeks about the time of the vernal equinox. It may then be perceived in the western sky after sunset, extending from the horizon upwards as far as the Pleiades. It has its base in the horizon, and thence diminishes gradually in breadth, tapering finally in a lance-like point. Its axis may be said to coincide with the ecliptic, or nearly so. Its base may measure about 15° in breadth, and the angular distance from the horizon to its pointed extremity in the heavens may amount to 70°. But in point of fact its apparent dimensions are found to be liable to extensive fluctuations, depending on the latitude of the place of observation and on atmospheric circumstances. It is generally best seen in tropical countries. In temperate regions its light, even under the most favourable circumstances, appears ill defined. In the same manner as it is seen after sunset about the time of the vernal equinox, so it may be seen frequently before sunrise about the time of the autumnal equinox. A representation of the zodiacal light is given in Plate 3.

CHAPTER XVII.

The Stars—Their great number—The Constellations—Colours of the Stars—New Stars—Variable Stars—Double and Multiple Stars—Clusters of Stars—Distance of the Stars—Their proper Motion—General Distribution of the Stars in Space—The Milky Way—Nebulæ—Maps of the Stars.

When the stellar vault is surveyed on a fine clear night, the number of luminaries which spangle on its surface appears to be inconceivably great. This, however, turns out to be an erroneous impression. Argelander, an eminent German astronomer, devoted considerable attention to the numbering of the stars which are simply visible to the naked eye, and the result of his labours leads to the conclusion that for persons merely endued with ordinary powers of vision, the entire number of stars in the celestial sphere which are visible under such circumstances does not exceed 4000. Even in the case of persons gifted with acute vision, the number of stars visible to the naked eye in the whole celestial sphere does not exceed 6000.

The result is quite different when the telescope is employed as an instrument of observation. Multitudes of stars which were previously invisible come then into view, and the number increases with each accession to the optical power of the telescope. Sir William Herschel, in the course of his stellar observations, found on one occasion that in the brief interval of fifteen minutes no fewer than 116,000 stars passed through the field of view of his telescope. In many instances they appear congregated in the form of globular clusters of stars appearing together in thousands in the same field of view, and exciting the astonishment and admiration of the observer.

Astronomers have classified the stars according to their brightness. Thus the brightest of the stars are termed stars of the first magnitude, the next in order of brightness are denominated stars of the second magnitude; then follow stars of the third, fourth, fifth, and sixth magnitudes. The stars of the sixth magnitude are considered to include the smallest stars which are visible to the naked eye, at least, if we have regard merely to persons possessed of ordinary acuteness of vision. The same system of classification has been extended to telescopic stars. Thus we have stars of the seventh, eighth, &c., magnitudes, down to the fifteenth and sixteenth magnitudes.

The Constellations.—The ancient astronomers, with a view to promote the study of the stars, formed them into a number of distinct groups or constellations, to each of which they applied the name of some object, most frequently the name of an animal. Thus we have the constellation of Aries or the Ram, Taurus or the Bull, Leo or the Lion, and so on. Ptolemy, the famous Greek astronomer, to whom we owe the sole catalogue of stars which has come down to us from antiquity, has divided the celestial sphere into forty-eight constellations. Of these, twenty-one constellations are in the northern and fifteen in the southern hemisphere, while the remaining twelve occupy an intermediate zone termed the Zodiac, which included within its boundaries the apparent paths of the sun, moon, and planets. We may remark that this practice of grouping the stars into constellations was, however, familiar to the ancients long before the time of Ptolemy. It was also adopted by astronomers in all subsequent ages down to the present time. The twelve constellations of the Zodiac are:—Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, Pisces. Each of these

constellations was supposed to occupy 30° of the Zodiac, and the circumference of the latter being divided into twelve equal parts, called signs, each constellation was consequently represented by a sign of the Zodiac. The first in the order of the signs was Aries, then Taurus, and so on in the order which we have given above. Aries was selected as the first of the signs, because at the time of the discovery of the precession of the equinoxes, the point of intersection of the equator and the ecliptic, which constituted the starting-point for the measurement of the longitudes of the celestial bodies, was situated in the constellation Aries. Hence originated the expression, "the first point of Aries," so frequently used in astronomy. The discovery of the precession of the equinoxes showed, however, that the first point of Aries as thus defined was perpetually shifting its position with respect to the stars. In the present day it is no longer in the constellation Aries at all, still the name originally applied to it continues to be used as a convenient definition of the *movable* starting point for the measurement of the longitudes and right ascensions of objects in the celestial sphere.

The following are the twenty-one constellations situated north of the Zodiac :—

Ursa Minor	or	The Lesser Bear.	Auriga	or	The Charioteer.
Ursa Major	,,	The Great Bear.	Ophiuchus	,,	Ophiucus.
Draco	,,	The Dragon.	Serpens	,,	The Serpent.
Cepheus	,,	Cepheus.	Sagitta	,,	The Arrow.
Boötes	,,	The Herdsman.	Aquila	,,	The Eagle.
Corona Borealis	,,	The Northern Crown.	Dolphinus	,,	The Dolphin.
Hercules	,,	Hercules.	Equuleus	,,	The Little Horse.
Lyra	,,	The Lyre.	Pegasus	,,	Pegasus.
Cygnus	,,	The Swan.	Andromeda	,,	Andromeda.
Cassiopeia	,,	Cassiopeia.	Triangulum Boreale	,,	The Northern Triangle.
Perseus	,,	Perseus.			

The fifteen constellations south of the Zodiac are :—

Cetus	or	The Whale.	Crater	or	The Cup.
Orion	,,	Orion.	Corvus	,,	The Raven.
Eridanus	,,	Eridanus.	Ara	,,	The Altar.
Lepus	,,	The Hare.	Centaurus	,,	The Centaur.
Canis Major	,,	The Great Dog.	Lupus	,,	The Wolf.
Canis Minor	,,	The Lesser Dog.	Corona Australis	,,	The Southern Crown.
Argo Navis	,,	The Ship Argo.	Piscis Australis	,,	The Southern Fish.
Hydra	,,	The Water-Snake.			

These 48 constellations do not occupy the whole surface of the celestial sphere; between them there were left many spaces to which the system of designation did not extend. This circumstance suggested to several modern astronomers the formation of a number of new constellations, a step which has introduced much confusion into the nomenclature of the stars. Baily, who superintended the preparation of the British Association Catalogue, discarded the greater number of the modern constellations as unnecessary. For the same reason several constellations which are usually to be found in globes and charts are not included in the Star Maps of this Atlas (Plates 13-18).

Names of the Stars.—Several of the brighter stars are distinguished by proper names. Thus there are the stars Arcturus, Sirius, Capella, Regulus, Vega, Aldebaran. A few of such names have come down to us from the Greek astronomers, but we owe considerably more, as in the case of the two last mentioned, to the Arabians, who were assiduous cultivators of astronomy in the Middle Ages. In the beginning of the seventeenth century, Bayer, a German astronomer, introduced the practice of designating the brighter stars of each constellation by means of the letters of the Greek alphabet. Thus we have α Orionis, β Leonis, γ Leonis, η Coronæ, and so on. Again, a still greater number of stars are designated by a numeral placed

before them. Thus we have 19 Aurigæ, 21 Orionis, 61 Cygni, &c., &c. This practice of distinguishing the stars in each constellation was first introduced by Flamsteed in his great Catalogue of Stars.

New Stars.—When we survey the stellar vault from night to night and from year to year, we discern no perceptible change in the general aspect of the stars. The same stars continue to appear in the same parts of the firmament, and to present the same configurations. The question then naturally arises, Have the heavens presented in all ages an aspect identical with their present aspect? Have any of the stars disappeared from the stellar sphere, or have any new stars in the lapse of ages occupied for the first time a place in the heavens? The annals of astronomy throw some interesting light upon these questions. If we institute a comparison between the catalogues of astronomers in different ages, we are led to conclude that stars which have shone for ages in the stellar sphere are no longer visible. Much, no doubt, of this is due to the imperfection of the earlier catalogues, but still the whole question of the disappearance of stars from the firmament cannot be disposed of in this manner. On the other hand, history makes mention of the appearance of new stars in the heavens in several instances, respecting which no doubt exists. We might cite for example the new star which appeared in the time of Hipparchus, and which, according to Seneca, suggested to the illustrious astronomer of antiquity the idea of constructing a catalogue representing the places of all the stars in the visible heavens. Coming down to more recent times, we have two memorable examples of a similar phenomenon in the sixteenth and seventeenth centuries. In 1572 a new star of extraordinary brilliancy appeared in the constellation of Cassiopeia. Tycho Brahé has left upon record an interesting description of the circumstances of its apparition. When first seen, it was brighter than α Lyræ, Sirius, or Jupiter, and could only be compared with Venus when it is at its greatest brilliancy. Many persons who were gifted with good sight perceived it in the daytime even at noon. Gradually it diminished in brightness, and finally vanished in March 1574, after continuing visible during a period of seventeen months.

In 1604 a new star, which was considered to be equal in splendour to the star of 1572, suddenly appeared in the constellation of Serpentarius. As in the case of the latter star, it gradually faded in brightness, and, after continuing visible for about fifteen months, it finally vanished.

Colours of the Stars.—The prevailing colour of the stars is white. Some stars, however, such as Aldebaran, Pollux, Antares, and α Orionis, have a decidedly ruddy aspect, while again Arcturus and others are yellowish. In the heavens there are immense numbers of stars which to the naked eye appear single, but when examined with a telescope of sufficient power are found to consist in each instance of two stars in close proximity to each other. Many of these stars exhibit the beautiful phenomenon of a difference of colour in the two components. An attempt is made in Plate 11 to represent some stars of this class. Thus in β Cygni and ε Boötis the principal star is yellowish, the companion a beautiful blue. In δ Cassiopeiæ the principal star is green, the companion blue. In η Cassiopeiæ the principal star is yellow, the companion purple. In γ Andromedæ the principal star is yellow, the companion green. In the constellation, Argo Navis is a double star, the components of which are equally bright, but one is pale green while the other is rose colour. In the constellation Lepus, near the borders of Orion, is a star of the seventh magnitude of a deep scarlet colour, contrasting strongly with a white star of equal brightness seen in the same field of view.

Variable Stars.—Some of the stars when attentively observed are found to vary in brightness, completing the cycle of their phases in a certain definite interval of time. One of the most remarkable of this class is a star in the constellation of the Whale usually termed o Ceti. The

period of its variations of brightness has been determined to be 331d. 15h. 7 m. It is generally invisible to the naked eye for about five months. Then it gradually increases in brightness, insomuch that in about three months hence it becomes equal to a star of the second magnitude. In this state it remains for about fifteen days, and then diminishes in brightness according to the same gradations as those which characterised its previous increase. Another interesting example of such stars is β Persei, or Algol, as it is usually called. For about two days thirteen hours and three-quarters it appears like a star of the second magnitude; then it declines in brightness, and so rapidly that in three hours and a half it resembles only a star of the fourth magnitude. From this phase of brightness it again increases in like manner as it previously diminished, and finally returns to its original phase of brightness in a period of two days twenty hours and three-quarters. Many more of such variable stars have been discovered, and the number is gradually increasing.

In the class of variable stars, we may, perhaps, include a star in the constellation *Corona Borealis* which has recently exhibited remarkable fluctuations of brightness. A few years since this star was estimated by Argelander to be of the 9½ magnitude. On the 12th of May 1866, it was suddenly perceived to be of the 2d magnitude. Henceforward it gradually declined in brightness, until, about the middle of June, it resembled only a star of the 9th magnitude. Mr Huggins made spectroscopic observations of this star on the occasion of its sudden change of brightness, and obtained some interesting results.

Double and Multiple Stars.—Allusion has already been made to the existence of double stars in the stellar heavens. In many of such instances it has been discovered that one of the two component bodies is revolving round the other; or, more strictly, that both bodies are revolving round their common centre of gravity. Plate 11 contains graphic representations of the orbits of two well-known double stars, ζ Herculis and γ Virginis. In the case of ζ Herculis the companion star effects a complete revolution round the principal star in thirty-six years. The physical connexion of the two component stars was originally discovered by Sir William Herschel in 1782, so that it has already performed two complete revolutions. γ Virginis was first remarked as a double star by Bradley in 1718. In 1780 the elder Herschel found that the distance between the two component stars was 5".6. Since that time the two stars continued to approach each other until 1836, when the one star came to be superposed upon the other, and both appeared as one star. Since 1836 they have again been opening out from each other, and now (in 1868) they appear to be about 3" apart. The movements of double stars have established the important fact that the remote bodies of the sidereal universe are controlled in their movements by the same law of attraction as that which governs the movements of the various bodies of the planetary system. In addition to double stars, there are systems composed of three or more component bodies. Thus ζ Cancri offers the example of a triple star, consisting of a closely double star and a more distant companion. Again in ε Lyræ we have an instance of a quadruple star. In inferior telescopes it presents simply the phenomenon of a double star, the component bodies of which are considerably apart, but in instruments of greater perfection the two constituent bodies are each resolved into two others.

Clusters of Stars.—Besides systems of stars consisting of a definite number of constituent bodies, the stellar heavens are enriched by globular clusters of stars which number hundreds, in many instances thousands, of constituent bodies. Objects of this class may be said to be visible *as such* only in telescopes. Those that are visible at all to the naked eye generally exhibit the aspect of nebulous objects. Plate 11 contains a representation of the well known cluster of stars termed the Pleiades, including the names of the principal stars. Although

in general only seven or eight stars are visible to the naked eye, the telescope reveals the existence of several hundreds in the group. A representation is also given in Plate 11 of three other remarkable clusters of stars—the cluster in Hercules, the cluster ω Centauri, and the cluster 47 Toucani.

The cluster in Hercules is situate in the straight line joining the stars η and ζ of that constellation. It was discovered by Halley in 1714, but it was regarded by the English astronomer as a nebula, and it was not until Sir William Herschel examined it with the powerful telescopes of his own construction that it was found to consist in reality of a cluster of closely-congregated stars. Herschel has estimated the number of stars in this cluster to amount to not less than 14,000!

The cluster ω Centauri is situated in the southern hemisphere, and as its declination is 46° 35′, it is not visible in northern latitudes. Sir John Herschel, who observed this remarkable object at the Cape of Good Hope, describes it as presenting to the naked eye the aspect of a dim round cometic object resembling a star of the 4.5 magnitude. "Viewed in a powerful telescope, it appears as a globe of fully 20′ in diameter, very gradually increasing in brightness to the centre, and composed of innumerable stars of the 13th and 15th magnitudes." The cluster 47 Toucani is described by the same astronomer as a magnificent object, the stars composing it being of the 14th magnitude, immensely numerous and compressed.

Distance of the Stars.—When Copernicus propounded the system of the universe according to which the earth revolves round the sun, it was argued by his opponents that, under such circumstances, the stars ought to exhibit a change of apparent position, depending on the variable position of the earth in its orbit. It was known that if the earth really revolved round the sun its orbit must be considerable, and consequently, if the apparent position of a star were determined at two opposite extremities of a diameter of the terrestrial orbit, it was reasonable to suppose that a parallactic displacement of the star would be discernible. No such change of place could, however, be detected, even by the nicest observations of astronomers, and this was considered by many of the contemporaries of Copernicus as constituting an insuperable objection to his theory. Copernicus met his opponents by asserting that the distance of the stars is so inconceivably great that the diameter of the earth's orbit is a mere point in comparison with it, and therefore there could be no sensible parallax of the stars. Henceforward till within the last thirty years this was the only response which could be given to the objection urged by the opponents of the true system of the universe.

Researches of Bessel and Henderson.—Since the application of the telescope to the determination of the apparent positions of the heavenly bodies, many persevering attempts have been made to determine the parallax of some of the more conspicuous of the stars, and although positive results were frequently supposed to be obtained, yet upon closer scrutiny they were found to be illusory. It was only in the year 1837 that the parallaxes of two stars, 61 Cygni and α Centauri, were ascertained beyond all doubt, the former by the German astronomer Bessel, the latter by the late Professor Henderson of Edinburgh. According to Bessel, the parallax of 61 Cygni is 0″.34. This result implies that the distance of the star from the earth is fifty-eight billions of miles. Light from the star, travelling as we know light *does* travel, namely, at the rate of 186,000 miles in a second of time, would not reach the earth in less than about ten years. Again, Henderson found from his observations of α Centauri, made at the Cape of Good Hope, that the parallax of the star amounts to nearly 1″. This implies a distance of about twenty billions of miles. Light would occupy about three years in passing from the star to the earth.

Researches of Peters and Struve.—The parallaxes of several other stars have been

determined with a considerable degree of certainty, but in no instance has a star been discovered to be so near to the earth as either of the two just mentioned. It may be presumed that in general the brighter stars are nearer to the earth than those which shine by a fainter light. Professor Peters has investigated the parallax of stars of the second magnitude, and has found its mean value to amount to 0".116. Assuming this result to be true, it follows that light in general occupies twenty-eight years in passing from a star of the second magnitude to the earth. Struve, by combining the parallax of the stars of the second magnitude, as thus determined by Professor Peters, with other results obtained by himself respecting the relative distances of the stars, has determined the absolute distance from the earth of the stars of different degrees of brightness. In this manner he has found that, in general, the parallax of a star of the sixth magnitude is such that light occupies one hundred and twenty years in traversing the space which intervenes between the star and the earth. He has further found that the time occupied by light in passing from the smallest star visible in the 20-foot reflecting telescope of Sir William Herschel to the earth amounts to not less than 3541 years!

Motion of the Solar System in Space.—The general host of the stars have been termed *Fixed Stars*, in contradistinction to the planets, the apparent positions of which are obviously in a state of continual change. It has been established, however, by the researches of modern astronomers, that many of the stars are perpetually but very slowly undergoing a change of apparent position in the celestial sphere. Fresh indications of the existence of such a proper motion are emerging every year from the observations of astronomers, and the probable conclusion is that in the lapse of ages all the stars of the firmament will be found to be endued with a proper motion. The consideration of the stars whose proper motions have been already established suggests another question of profound interest in astronomy. According to the Copernican theory of the universe, the sun is a star. The circumstance, then, of many of the stars being found to have a proper motion affords good ground for supposing that the sun also (and of course its *cortège* of attendants) has a proper motion in space. If such a motion of the solar system really existed, it would follow that the observed motions of the stars would only be *in part* due to a real motion of the stars themselves, the remainder being merely a parallactic displacement arising from the movement of the solar system in space. Modern astronomers, setting out from this point of view, have rigorously established the fact of the existence of a real motion of the solar system in space, and, what is more, have ascertained the point in the celestial sphere toward which it is being transported from year to year. According to the most recent researches, this point is situated in—

Right Ascension, ...	263° 44'.
Declination North, ...	35° 0'.

The point indicated by these numbers is situated in the right line joining the two stars π and μ of the Constellation Hercules, the distance of the point from π being to its distance from μ as one to three.

The Sun is a Star.—A combination of the results respecting the proper motions of the stars with the results of parallax has enabled astronomers to determine the absolute movement in space of the sun and several of the stars. In this manner it has been found that the sun, with all its attendant planets and satellites, is travelling through space at the rate of 150 millions of miles in a year. On the other hand, the star α Centauri is traversing space with the speed of 350 millions of miles in a year; while again the annual movement of 61 Cygni amounts to 1290 millions of miles. These numbers are fairly comparable with each other, and seem to indicate that the sun is no other than a star.

General Distribution of the Stars in Space.—Every person must have remarked the grand arch of faint light which spans the celestial vault on a clear starry night, and to which the name of the Galaxy, or the more familiar appellation of "The Milky Way," has been assigned. The zone represented by this arch (for it in reality encircles the celestial sphere) is found to be vastly richer in stars than any other region of the stellar heavens, and astronomers, pursuing this idea, have discovered that the stars diminish with remarkable regularity as we proceed from a great circle of the celestial sphere coinciding with the mean course of the Milky Way, to the poles of the same great circle. Sir William Herschel endeavoured to account for this fact by supposing the stars to be distributed not indiscriminately in the heavens, but in the form of an immense stratum or disc, near the centre of which the sun, with its attendant planets, is placed. A section of this stratum is exhibited in Plate 11. It is clear that, to an observer at the sun, the number of stars seen towards B, D, or F will be much greater than the number seen towards C or A, which are in the directions of the thickness of the disc. The shortening of the radial distance passing through E is intended to represent the bifurcation of the Milky Way, so strikingly observable on a fine clear night.

Researches of Struve.—Herschel in these speculations supposed the stars to be distributed uniformly in space. Struve, however, has subsequently found that there is a gradual condensation of the stars towards the plane of the Milky Way, where it attains its maximum; and he has assigned a law of density, the results of which present a remarkable agreement with those derived from actual observation.

Nebulæ.—There are many celestial objects which present a nebulous aspect, and which, even when examined with the most powerful telescopes in existence, do not exhibit any indication of being resolvable into stars. Such objects we are bound to consider in the present state of astronomy as composed of nebulous matter. We must confine ourselves in this rapid sketch to a few remarks on two or three of the more conspicuous of such objects which have been discovered in the heavens.

Nebula of Orion.—This nebula was first made known to the scientific world generally by the celebrated Dutch astronomer Huyghens, 1656; but it appears from recent historical researches that it was seen by Cysatus, a Swiss astronomer, as early as the year 1618. It is one of the most remarkable objects in the stellar heavens. Huyghens was so struck with its singular aspect, situated as it was in the midst of an intensely dark region of the celestial sphere, that he suggested whether the phenomenon might not arise from our looking through an aperture in the heavens into a luminous region beyond. In the centre of this nebula are four well-known small stars forming a trapezium. Many other small stars are seen scattered over the area of the nebula, but hitherto, unlike many other objects of the same class, it has not offered any decided indications of being resolvable into stars. The view of this nebula (Plate 12) is from a drawing by the late Professor G. P. Bond of Cambridge, U.S., whose observations were made with a magnificent equatorial of fifteen inches aperture.

Nebula of Andromeda.—This nebula is visible to the naked eye. It was so seen as early as the tenth century. The attention of astronomers was first especially directed to it in 1612 by Simon Marius, a German astronomer, who described its aspect by comparing it to the appearance presented by a candle shining through a horn. In telescopes of moderate power it bears a considerable resemblance to the elliptical nebula, fig. 1, Plate 12. The view of it in Plate 12 is by the late Professor Bond. According to the observations of that astronomer, it extends $2\frac{1}{2}°$ in length, and rather more than 1° in breadth. The two very remarkable dark parallel streaks seen in the drawing were discovered by Professor Bond. He states that it requires a good deal of attention to see them, even under the most favourable circumstances. This

nebula, like that of Orion, has offered some faint indications of resolvability, but in neither case has it been really established whether the nebula is merely an agglomeration of stars, or whether it is composed of some essentially nebulous substance.

Dumb-Bell Nebula.—This object is situated in the constellation Vulpecula, and forms No. 27 of the well-known Catalogue of Nebulæ of the French astronomer Messier. In telescopes of ordinary power it simply resembles a double nebula, the contiguous parts of which extend to each other so as to be nearly in contact, and as such was registered by its discoverer. Sir John Herschel, who observed it with a twenty-foot reflector, describes it as an irresolvable nebula, with an elliptical outline of faint light enclosing the two masses. The telescopes of the late Earl of Rosse have resolved the nebula into stars as represented in the figure.

Annular Nebulæ.—A remarkable object of this class is represented in Plate 12. It is situated in the line joining β and γ Lyræ, and is about equally distant from each of those stars. In telescopes of moderate optical power it presents the aspect of an oval ring well defined at the edges. In the twenty-foot reflector of Sir John Herschel the central vacuity does not appear quite dark, but is filled in with a faint nebulous substance like a gauze stretched over a hoop. In the powerful telescopes of Lord Rosse it is resolved into small stars, and shows filaments of stars adhering to its edges.

Spiral Nebulæ.—The discovery of all the nebulæ of this class is due to Lord Rosse, whose powerful telescopes alone have served to disclose their real structure. An interesting specimen of such nebulæ is represented in fig 6, Plate 12. It is No. 51 of Messier's catalogue. In its vicinity appears a smaller nebula. Sir William Herschel has described it as a bright round nebula surrounded by a halo of light, and attended by a companion nebula. The telescopes of Lord Rosse have demonstrated that its structure consists of a series of spiral convolutions arranged with remarkable regularity. Another of the spiral nebulæ is represented in fig. 7, Plate 12.

Figures 1, 2, 3, 4, and 5 of Plate 12 exhibit nebulæ of different forms, derived from the delineations of objects of this class in the northern and southern hemispheres, given by Sir John Herschel in the 'Philosophical Transactions' for 1833, and in his 'Results of Astronomical Observations at the Cape of Good Hope.'

Maps of the Stars.—Plates 13-18 are devoted to a system of maps of the stars, which have been constructed on the gnomonic projection of the sphere. The Catalogue of Stars published by the British Association for the Advancement of Science has been adopted as the authority in laying down the positions of the stars. The Maps include all stars down to the $5\frac{1}{2}$ magnitude, but to avoid having too many classes, the stars of $1\frac{1}{2}$ magnitude are set down in the maps as first magnitudes, those marked $2\frac{1}{2}$ as second magnitudes, and so on.

The stars are represented as they really appear in the stellar vault, not reversed as on a celestial globe. Instead of north and south declinations, north polar distances are given. Nebulæ and clusters are marked *Neb.* *Var.* indicates that the object is a variable star. *Nova* indicates a new or temporary star.

CHAPTER XVIII.

Decomposition of Light by Newton—Fraunhofer's Lines—Experiment of Brewster on the Absorption of Light—Kirchhoff's Explanation of Fraunhofer's Lines—Application of Spectral Analysis to Astronomy—Results of Researches.

Decomposition of Light.—When a beam of solar light is transmitted through a small aperture into a dark chamber it appears perfectly white, as it comes to the eye reflected by the particles of dust which lie along its path. Let us, however, place a glass prism in the course of the light, and examine the result. The direction of the rays will now appear changed, in consequence of the refraction which they experience in passing through the glass. But this is not all. If we had received the light upon a white screen, it would have presented simply the aspect of a white spot. When the prism, however, is placed in the course of the light, the projection of the latter on the screen is no longer a white spot, but forms an oblong space, exhibiting the beautiful variety of colours which we admire in the rainbow. These colours are violet, indigo, blue, green, yellow, orange, red—the violet deviating most from the course of the beam, then the indigo, and so on until we finally arrive at the red, which exhibits the least deviation from the original course of the beam. It appears then that a beam of solar light, instead of being homogeneous, is composed in reality of seven colours of different degrees of refrangibility. This great discovery was made by Newton. The oblong space thus received upon the screen is termed the prismatic spectrum. It is obvious from what has been already stated that the violet rays occupy one extremity of the spectrum, and the red rays the other extremity.

Dark Lines of the Spectrum.—When the spectrum is examined with a telescope, it is perceived to be furrowed in a direction transverse to its length by a number of dark lines, which are found to occupy an invariable position, and to be altogether independent of the length of the spectrum or the angle of the prism. These lines, or rather a few of the more prominent ones, were first remarked by Wollaston in 1802. A few years subsequently, in 1815, they attracted the attention of Fraunhofer, who measured with great care and precision the relative positions in the spectrum of between six and seven hundred lines, and who conducted his experiments with such ability and success that ever since the dark lines in the solar spectrum have received the appellation of *Fraunhofer's lines.*

The Spectrum of an Incandescent Solid or Molten Body is Continuous.—When the light emanating from a solid or molten body in a state of incandescence is similarly intercepted by a glass prism, the resulting spectrum is found to correspond to the solar spectrum in so far as regards the variety of colours and their order of succession, but differs from the solar spectrum in this important respect that the continuity of colour is nowhere interrupted by the presence of dark bands analogous to Fraunhofer's lines. Thus, the electric light which results from the incandescence of two charcoal points forms a continuous spectrum, and the same effect is produced when the source of light is directly traceable to the incandescence of any other solid or molten body.

Bright Lines formed by the Spectra of Metallic Flames or Luminous Gases.—Finally, if we form the spectrum of a gaseous body in a luminous state, we shall obtain a result different from either of the two which have been already considered. The spectrum will now consist of a few bright bands, separated from each other by dark spaces. For instance, if the luminous vapour of the metal sodium be employed as the source of light, the

resulting spectrum consists simply of a bright yellow line. Each metal produces a spectrum characterised by its own peculiar lines, and thus it has become possible to detect the existence of extremely minute ingredients of a metal in a substance, by an analysis of the spectrum which the compound material exhibits. To this mode of investigation is consequently due the discovery of the metals *cæsium* and *rubidium* by Bunsen, of *thalium* by Crookes, and of *indium* by Reich and Richter.

Plate 14 exhibits the spectra of the solar light, and of the luminous vapours of several of the metals. A few only of the more prominent of the dark lines are set down in the solar spectrum. In delicate experiments the characteristic yellow line of sodium is seen to be double, with a dark narrow space between the two constituent lines. Bunsen proved that by means of a spectral analysis it would be possible to detect the presence, in any substance, of a quantity of sodium amounting to not more than the two hundred-millionth of a grain.

The spectrum of lithium consists of one bright crimson line and one fainter orange line. The spectrum of strontium exhibits eight brilliant lines—six red, one orange, and one blue line. The spectrum of cæsium exhibits two blue lines. The positions of the lines in these metals are laid down in Plate 14.

Absorption of Light by Nitrous Gas.—The origin of the dark lines in the solar spectrum was generally considered by physicists to be due to a process of absorption somehow occasioned by the passage of the sun's rays, either through the solar or the terrestrial atmosphere. This view received strong support from a remarkable experiment performed by Sir David Brewster in 1822. Having interposed nitrous gas between a prism and a source of light which independently formed a continuous spectrum, he perceived the colours to be furrowed by dark bands analogous to Fraunhofer's lines. It was ascertained, indeed, upon examination, that the positions of those bands were not identical with the positions of any of the lines in the solar spectrum, but the experiment was valuable, inasmuch as it demonstrated that dark lines might be produced in a continuous spectrum by a process of physical absorption.

Identity of the Double Sodium Line with the Dark Line D of the Solar Spectrum.—As a further step towards an explanation of the mystery of the dark lines in the solar spectrum, it was remarked that the position of the double sodium line coincided exactly with the position of the line D in the solar spectrum. This important fact appears to have been first recognised by Fraunhofer.

Kirchhoff's Generalisation.—It was reserved for the eminent German physicist, Professor Kirchhoff, to group together the various facts relating to the bright and dark lines of the spectrum under one general law, which he established by experiment, and which may be thus enunciated:—*Heated vapours absorb rays of light falling upon them of the same refrangibilities as those of the rays which they emit.* Thus if we form a continuous spectrum by means of the electric light, and if, in the path of the issuing beam of light, before it enters the prism, we interpose the flame of sodium, the yellow of the spectrum will be furrowed by a dark band. If we remove the sodium flame the yellow will reappear; and as often as the sodium flame is placed in the path of the beam, so often will the yellow of a definite refrangibility be replaced by a dark band in the spectrum. Kirchhoff ascertained by experiment that a similar effect was produced when for sodium the metals lithium, potassium, strontium, calcium, or barium were substituted.

Explanation of the Dark Lines on the Solar Spectrum.—We have here, then, a satisfactory explanation of the dark lines in the solar spectrum. If we suppose the sun to be a molten body in a state of incandescence, and to be encompassed by an atmosphere in which float the vapours of various metallic and other substances, then will those vapours intercept

the rays of light emanating from the incandescent body of the sun which are of the same refrangibilities as the rays which they emit, and hence will originate a series of dark lines in the solar spectrum conformably to what observation indicates. Hence, also, by a careful mapping of the lines in the spectra of terrestrial substances, we shall be enabled to ascertain whether any such substances exist in the atmosphere of the sun; for if we find, for instance, that the *bright* lines or bands characteristic of any of the metals correspond, line for line, with another series of *dark* lines in the solar spectrum, then, according to the law connecting the absorption and radiation of light, as experimentally established by Kirchhoff, we shall be warranted in concluding that the metal or substance in question exists in the sun's atmosphere.

Discovery of Substances in the Sun's Atmosphere.—In this way Kirchhoff discovered the existence of iron, calcium, magnesium, and various other substances, in the solar atmosphere. The conclusiveness of the evidence upon which our knowledge of the existence of such substances in the sun is based, may be inferred from a consideration of the circumstances connected with the case of iron, as adduced by Kirchhoff. A comparison of the spectrum formed by the luminous vapour of iron with the solar spectrum, exhibited *an exact coincidence* of about sixty bright iron lines, with as many dark lines of the solar spectrum. Nor is this all. The probability of a physical connexion between the two systems of lines is still further strengthened by the fact that the brighter a given iron line is seen to be, the darker, as a rule, does the corresponding solar line appear.*

In recent years the application of spectral analysis to astronomy has been prosecuted with great ability and success by Huggins and Miller in England, and by Padre Secchi, Janssen, and other eminent physicists on the Continent. The conjoint researches of Huggins and Miller have been especially remarkable for their extent and completeness. We shall here briefly notice some of the more interesting results at which they have arrived.

Spectra of the Moon, Planets, and Comets.—An examination of the moon's surface by the aid of the spectroscope has led to the same conclusion as regards the non-existence of an atmosphere which astronomers have derived from telescopic observations. On the other hand, the planets Jupiter and Saturn offer unequivocal indications of the existence of an atmosphere, a result which we might be led to expect from the appearances which those planets exhibit when viewed in the telescope. Comets would seem to be of gaseous structure, a result again agreeing with the indications derived from other sources.

Spectra of the Stars.—A spectral examination of many of the more conspicuous of the fixed stars leads to the conclusion that they are bodies mainly identical in structure with the sun. Their spectra are furrowed with dark lines analogous to those which are discernible in the solar spectrum. By a careful scrutiny of those lines, it has been established that there exist in the atmospheres of the stars the vapours of sodium, magnesium, iron, hydrogen, and various other terrestrial substances.

Plate 14 contains a representation of some of the more prominent lines which are observable in the spectrum of the star α Tauri, or Aldebaran, as it is more commonly termed. The line D indicates the presence of sodium. The line B (in reality three distinct lines) corresponds exactly in position to three bright lines in the spectrum of magnesium. The line C in the red of the spectrum of the star and the line F in the green are indicative of the existence of hydrogen.

* We have not deemed it necessary to enter into the history of the researches connected with this grand step of generalisation. It may be mentioned, however, that, in regard to the bright bands formed by the spectra of metallic vapours, some sagacious surmises were made by Wheatstone, Fox Talbot, and Professor Swan; and that the general question was all but elucidated by the experiments of Foucault and the theoretical views of Stokes and Anngström. Mr Balfour Stewart was also conducted by researches on the radiation and absorption of light and heat to a principle the development of which contains the solution of the question.

The line E (in reality double) is one of the numerous dark lines in the spectrum of the star which reveal to us the fact that iron forms part of its composition.

The same Plate contains a representation of some of the more prominent lines in the spectrum of α Orionis. The lines D, E, *b* indicate the presence of vapours of sodium, iron, and magnesium in the atmosphere of the star. Traces of calcium and bismuth have also been detected in it.

Spectra of Nebulæ.—Nebulæ, when subjected to the analysis of the spectroscope, have been found to exhibit merely a few bright lines indicative of a gaseous structure. This is true, however, only in regard to what may be considered as irresolvable nebulæ. Objects which are in reality clusters of stars, and which merely assume a nebulous aspect when viewed in inferior telescopes, exhibit, as might be expected, a continuous spectrum analogous to that derived from the solar light. The spectra of some nebulæ, however, both resolvable and irresolvable, exhibit anomalous features indicative of peculiarities of structure which cannot in the present state of astronomical physics be satisfactorily accounted for.

We may state that the possibility of obtaining, *at any time when the sun is visible*, spectra of the red prominences seen around the moon's limb during total eclipses of the sun, has been recently established by the independent observations of M. Janssen and Mr Norman Lockyer. M. Janssen, who observed the eclipse of August 17, 1868, in India, succeeded a few days afterwards in obtaining a series of full sunlight spectra of the red prominences. About the same time Mr Norman Lockyer, in England, after many fruitless efforts, quite independently achieved the same result. Any further remarks on this subject would in the mean time be premature. It may be stated, however, that the red prominences are manifestly of gaseous structure, and that traces of the presence of hydrogen have been detected in them.

CONCLUSION.

In concluding this brief survey of the heavens, the Author need scarcely remark, that his object has been, not to present the reader with a complete view of Astronomy, which would have been altogether inconsistent with the limits prescribed by the nature of the work undertaken by him, but rather to give such an exposition of facts and principles relating to the movements and physical constitution of the celestial bodies, as might serve to render more easily intelligible, and more interesting, the various representations contained in the accompanying Atlas.

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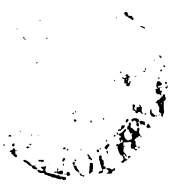
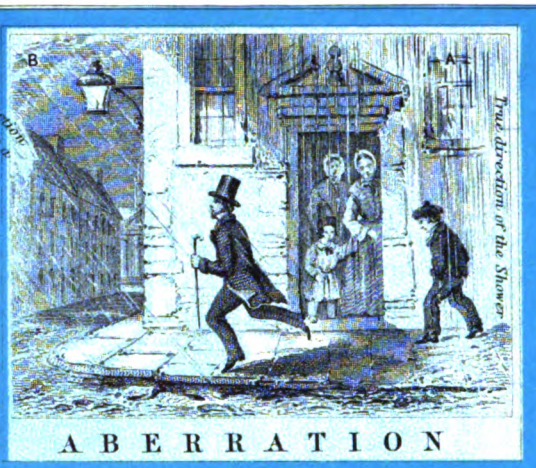


FIG.4.



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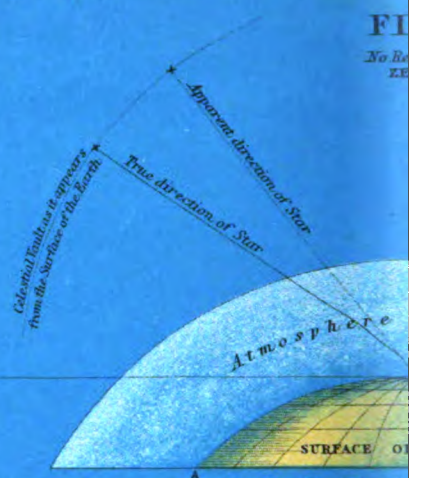

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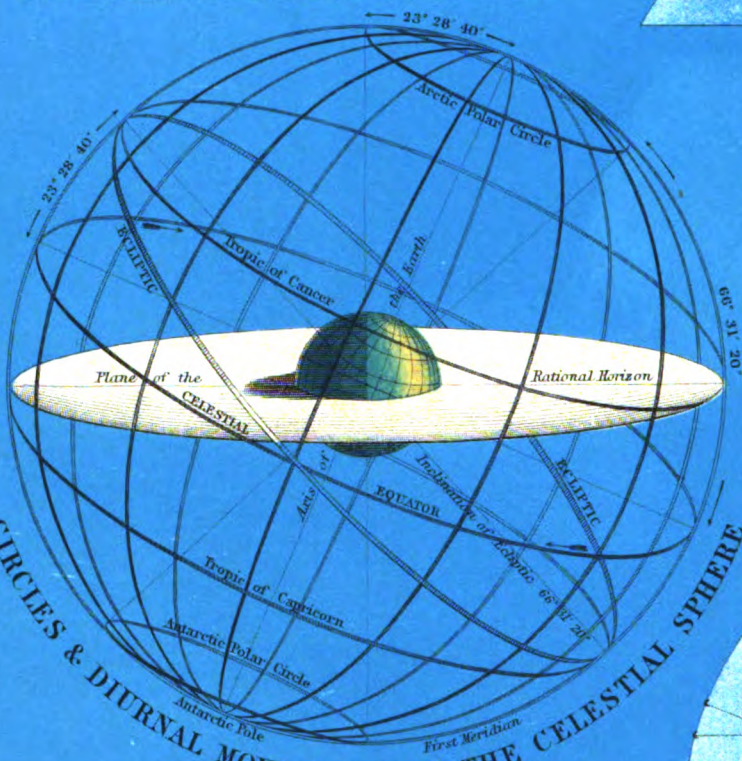

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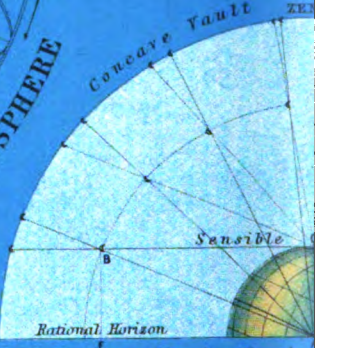


PARA

FIG. SUN 7.

PHASES OF THE INFERIOR PLANETS

FIG. 2.

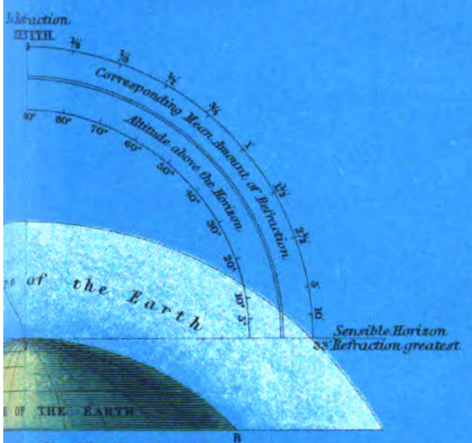


FIG. 5.

ABERRATION

ACTION

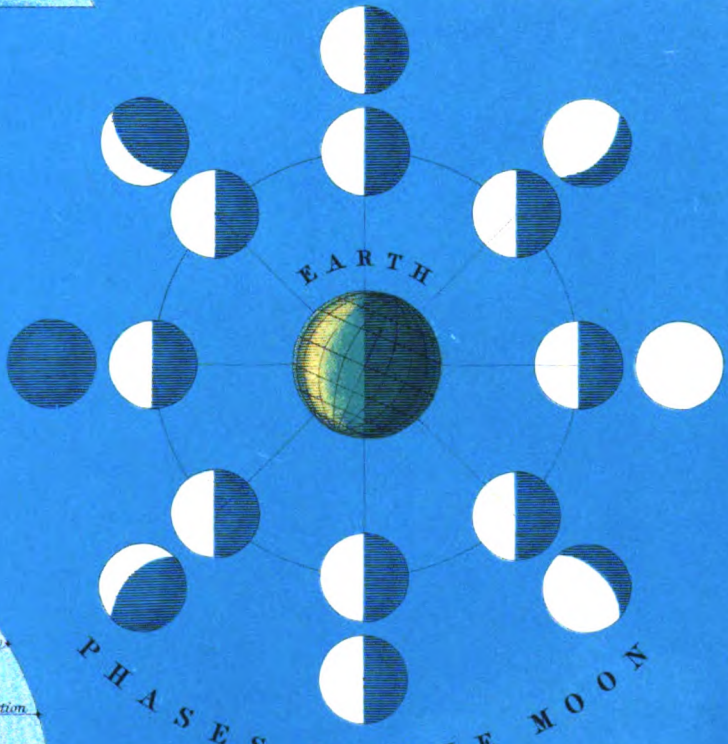
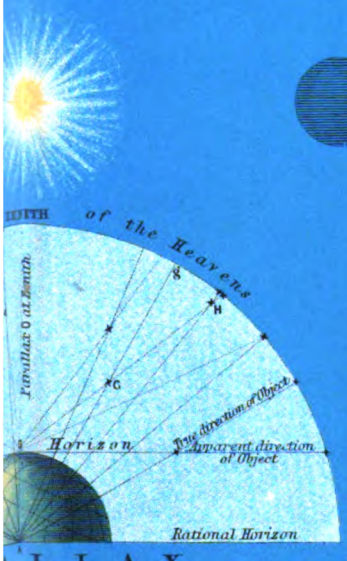


FIG. 6.



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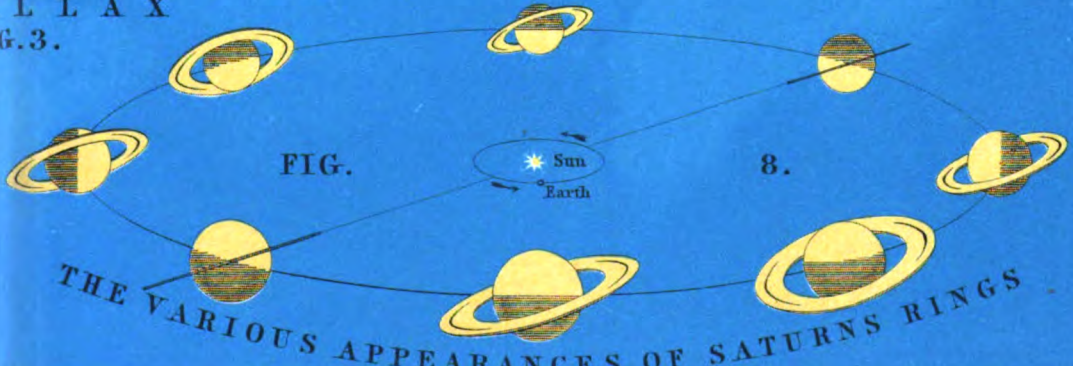

FIG. 8.

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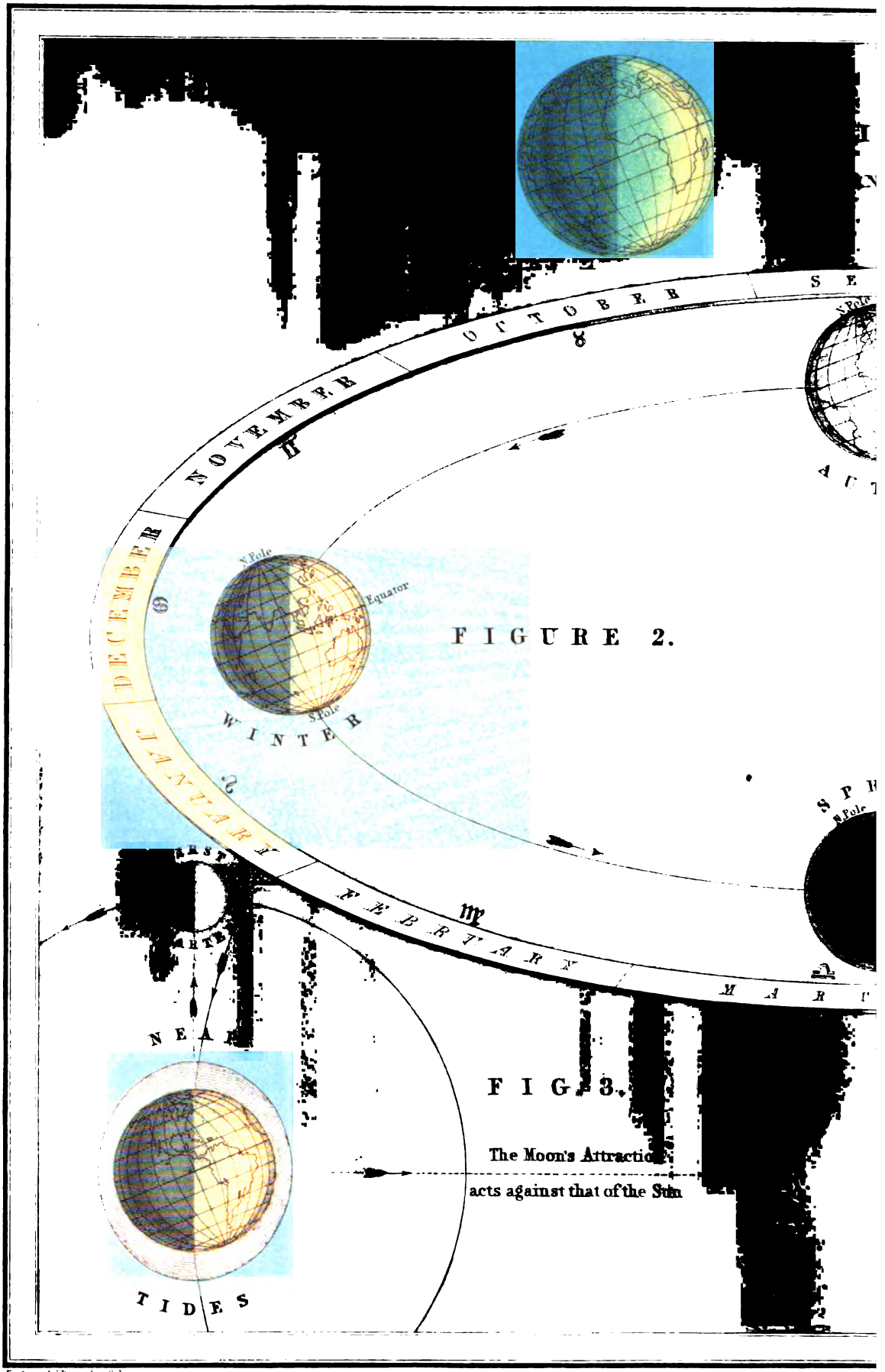

FIGURE 2.

FIG. 3.

The Moon's Attraction
acts against that of the Sun

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FIG. 1.

AND NIGHT

THE SEASONS

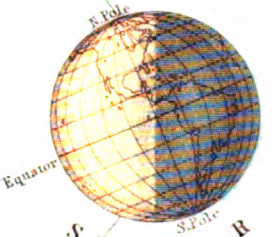


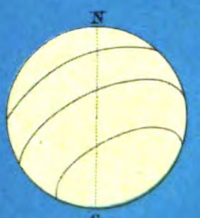
FIG. 4.

Attraction

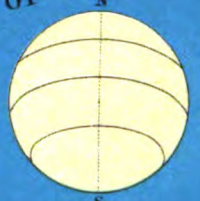
t of the Sun

Edinburgh & London

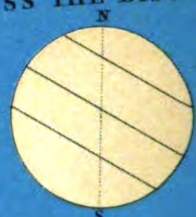
PATHS OF THE SPOTS ACROSS THE DISC OF T



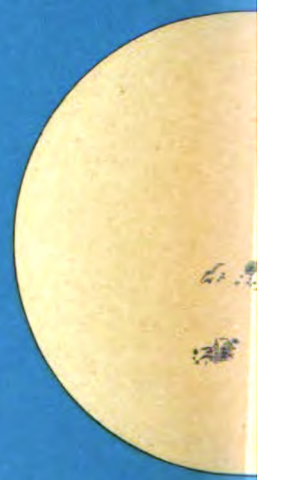
February



March

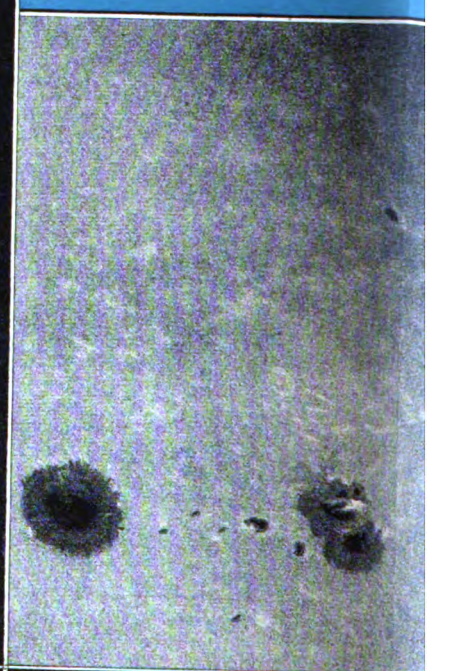


June



THE S
Viewed with a low power sl

THE ZODIACAL LIGHT.



SOLAR S
Viewed with high mag

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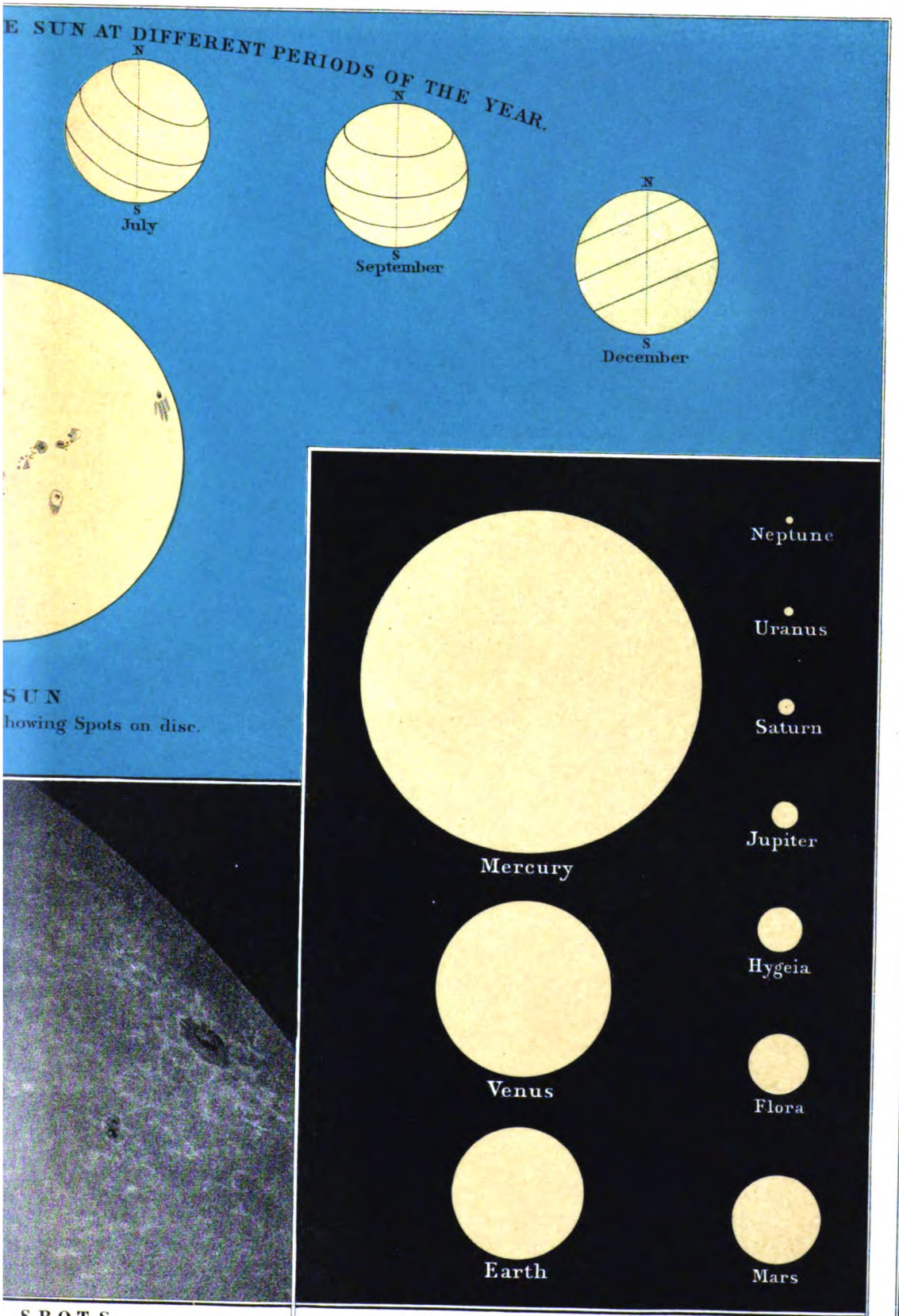
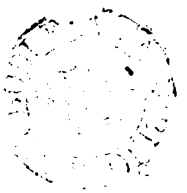


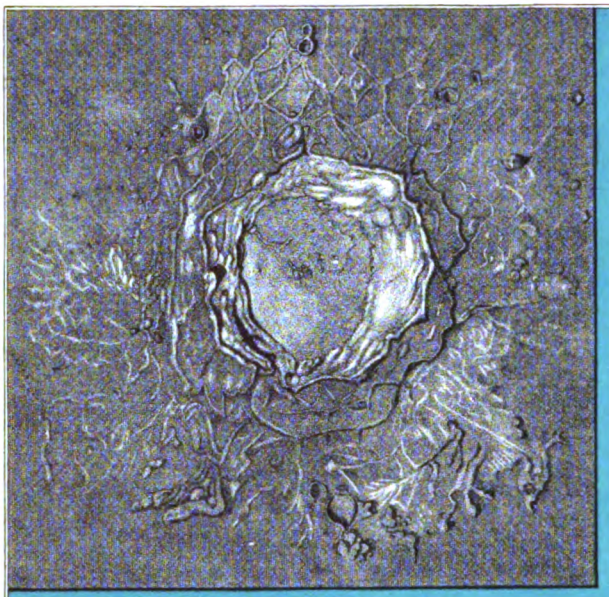
SPOTS
magnifying power.

APPARENT MAGNITUDE OF THE SUN
as viewed from the various Planets.

Edinburgh & London

by W. & A.K. Johnston, Edinburgh





The Crater of Copernico

Enlarged View of the Moon

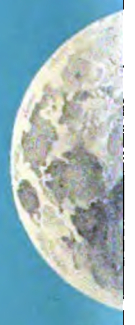
FIG.1. FULL MOON from a dr

PHASES OF

4 Days

5 Days

6 Days



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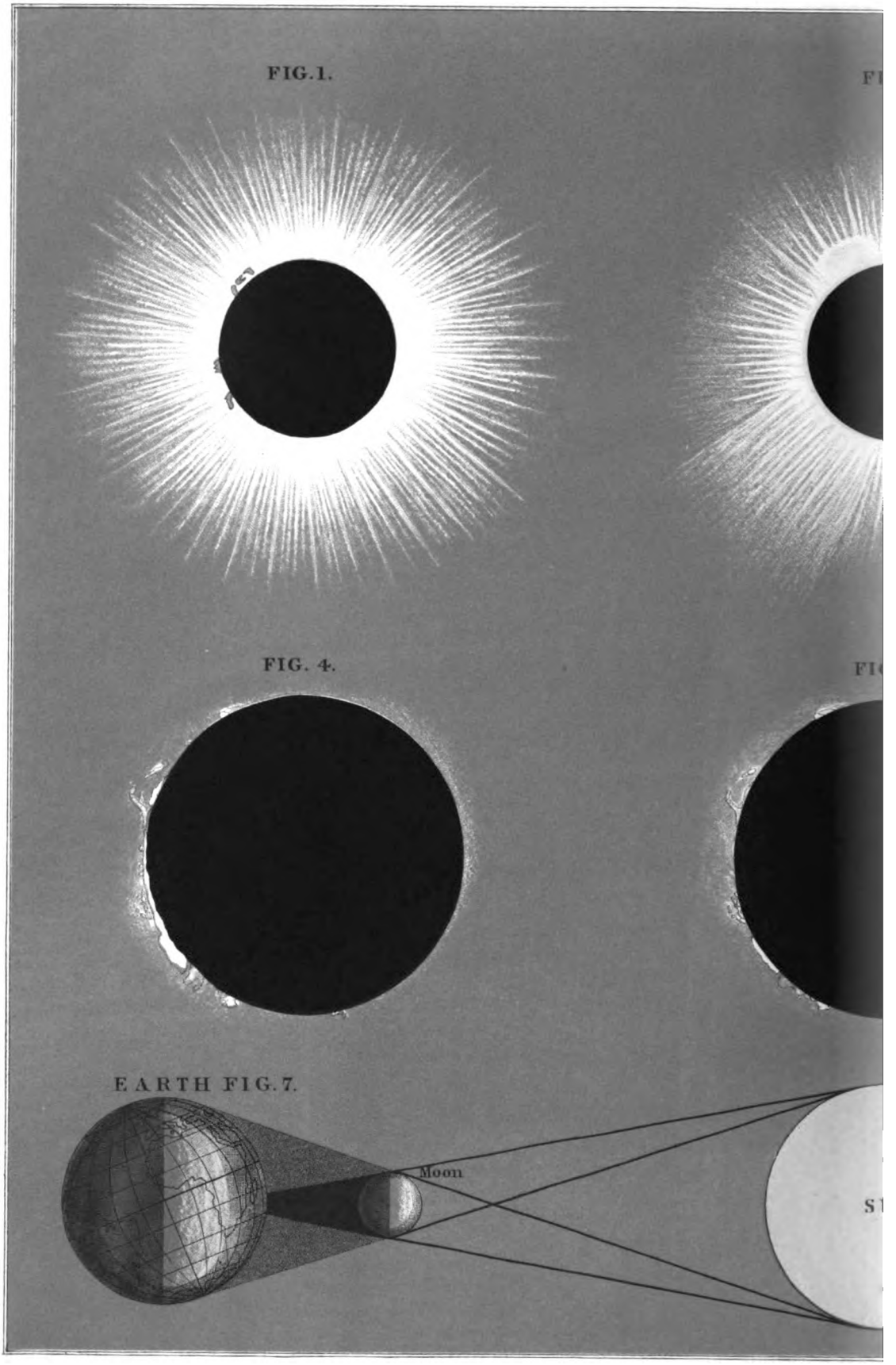

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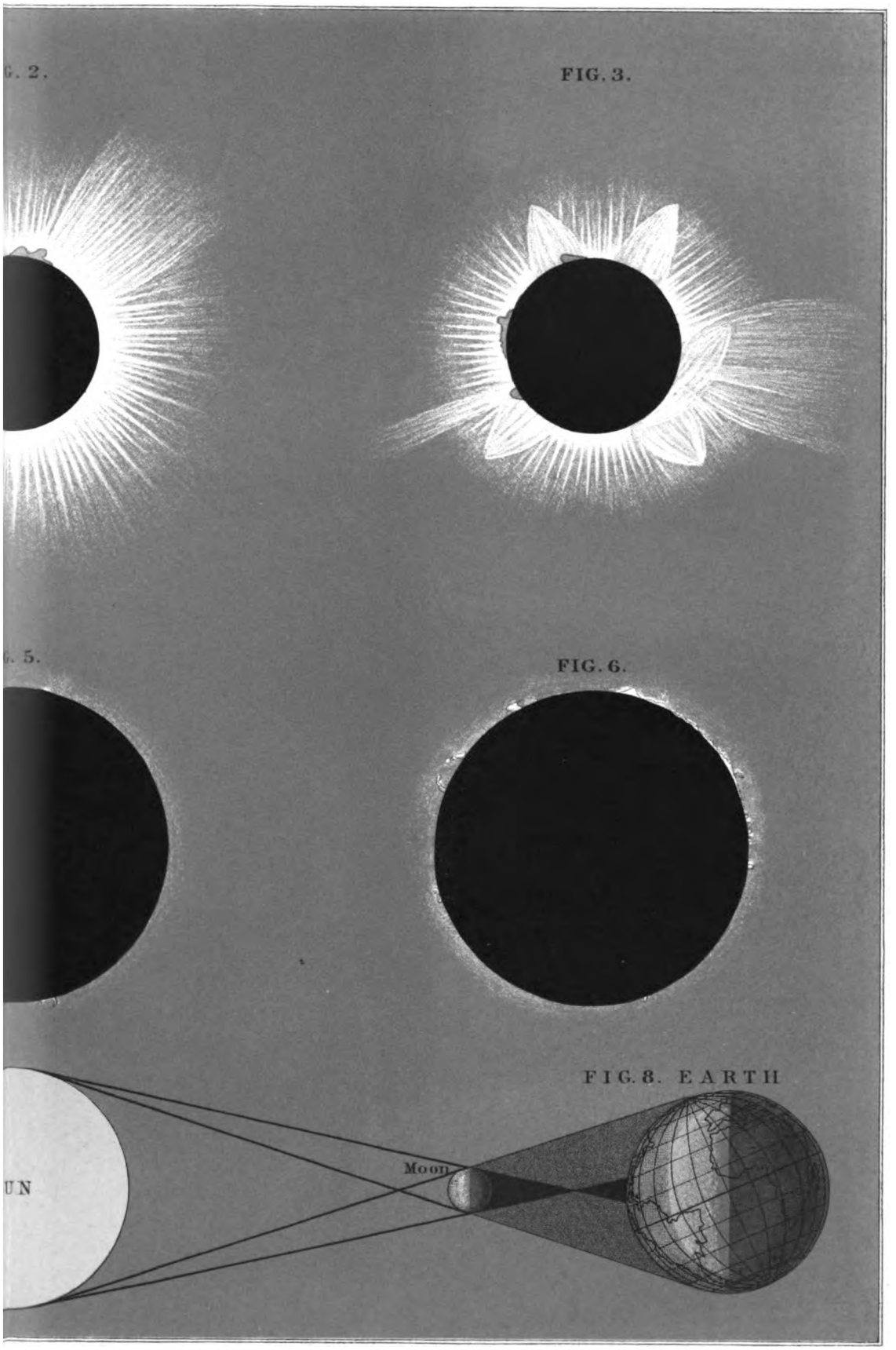

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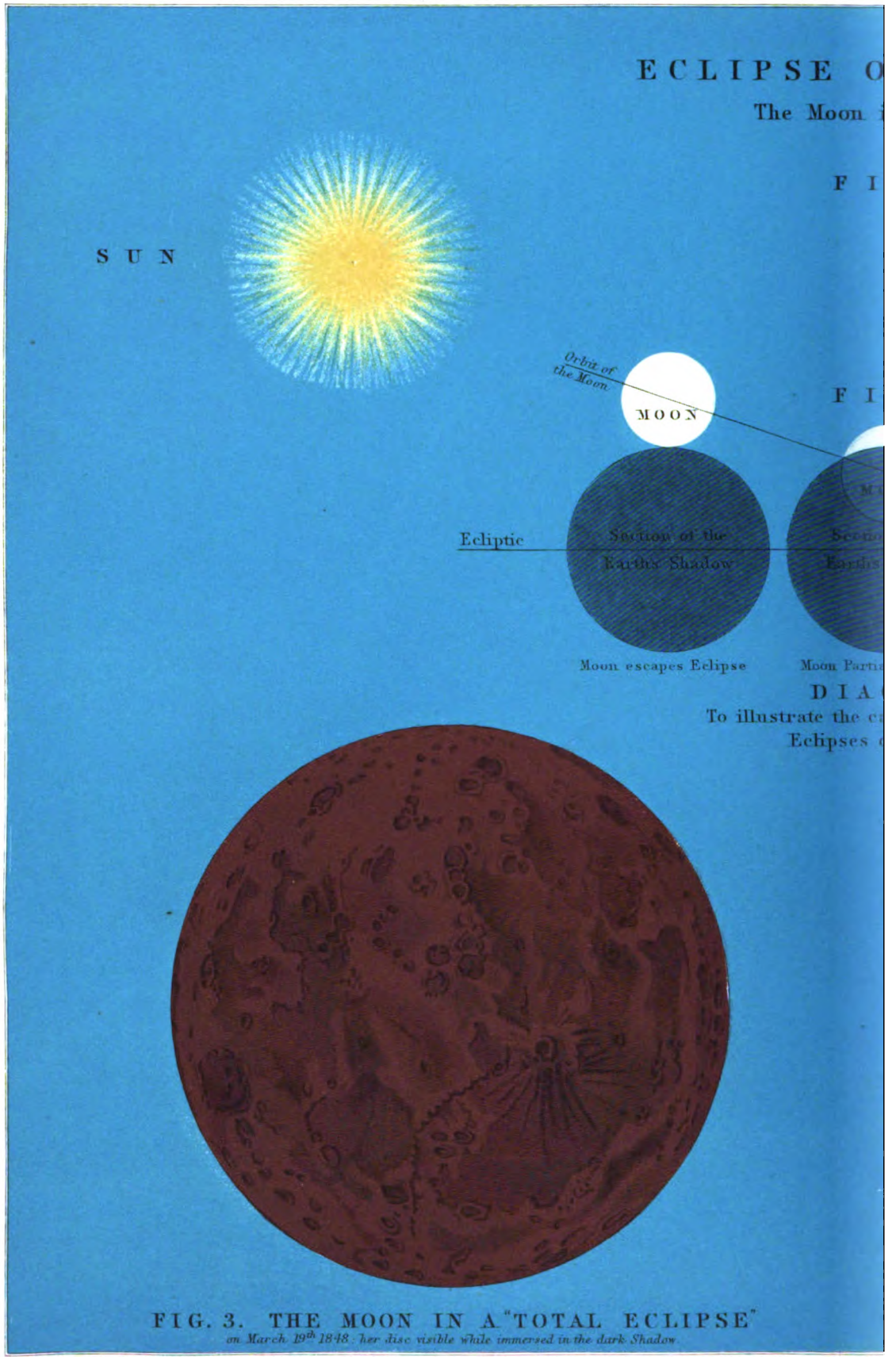

FIG. 3. THE MOON IN A "TOTAL ECLIPSE"
on March 19th 1848. her disc visible while immersed in the dark Shadow.

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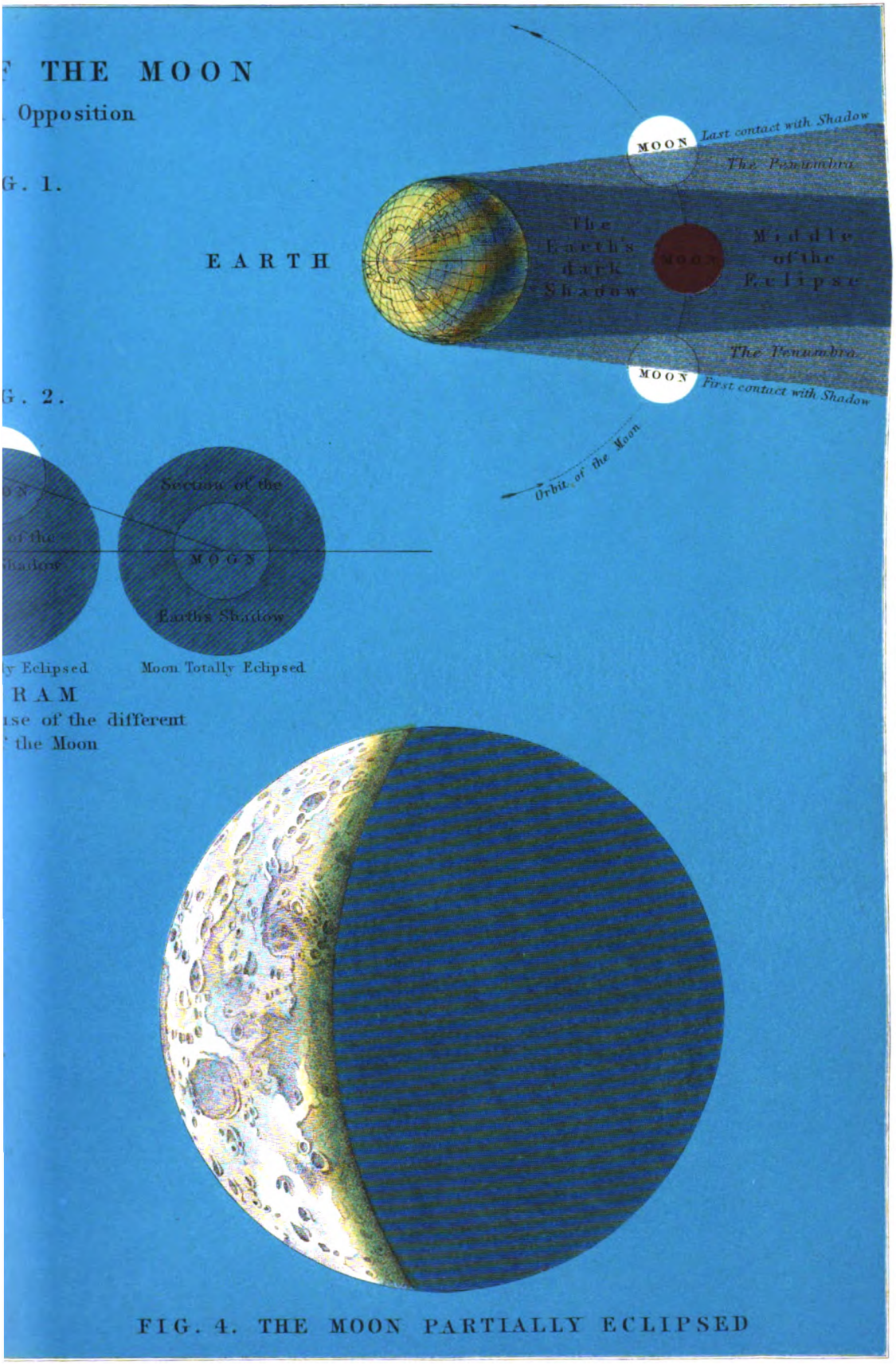

FIG. 4. THE MOON PARTIALLY ECLIPSED

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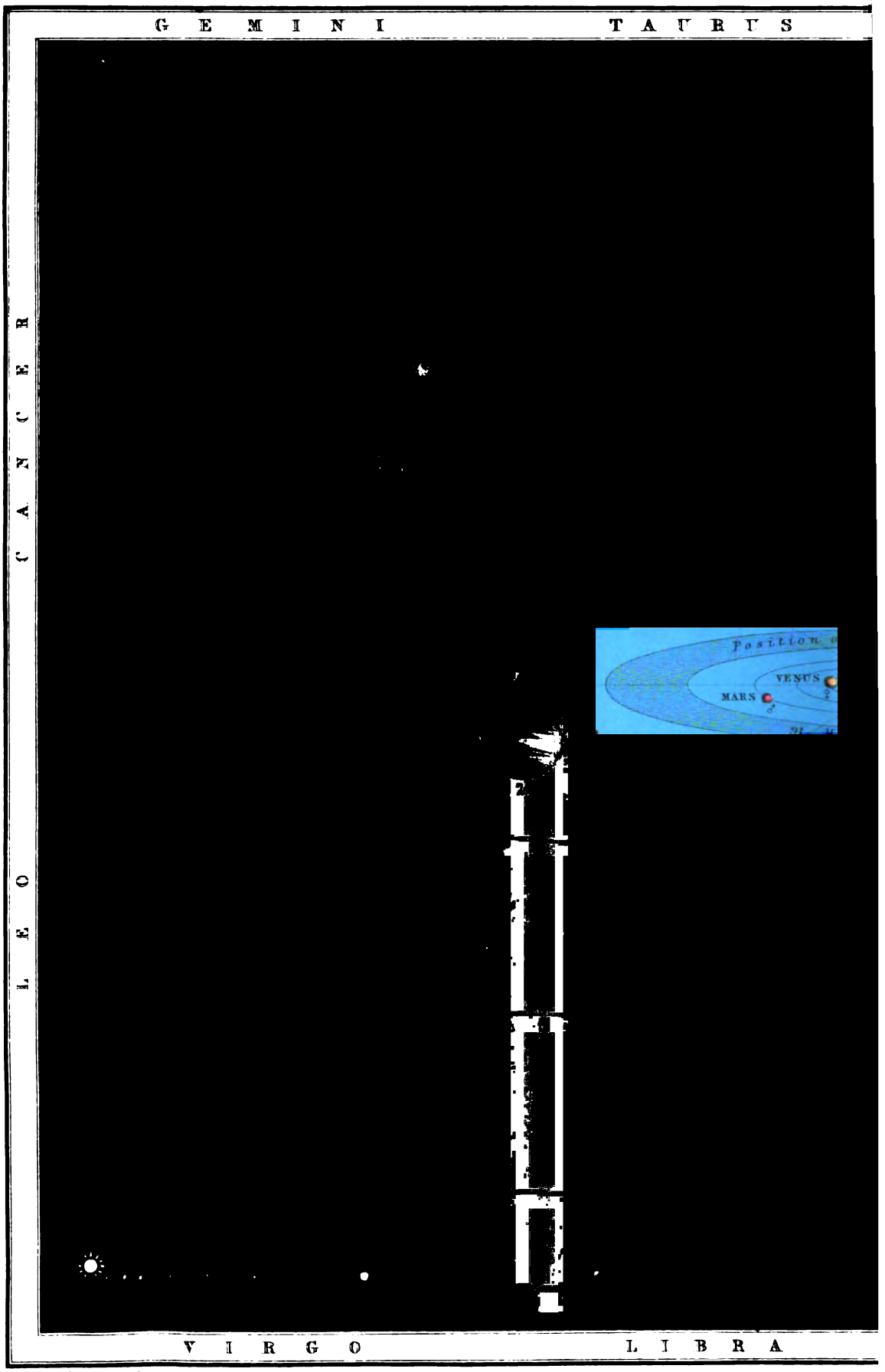

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A R I E S

P I S C E S

R SYSTEM

direction of the Planets motion,
he motion of their Satellites.

L E
of the Sun, Moon and Planets
IT AXES.

d. h. m.
25. 8. 10
27. 7. 43
1. 0. 5
0. 23. 21
0. 23. 56 mean Solar time.
1. 0. 37
0. 9. 55
0. 10. 16
Unknown.

NEPTUNE and his Satellite

SATURN and his Satellites

Jupiter

Orbits of the

MERCURY Moon EARTH Flora Hygeia

Planets

Saturn

Uranus

L E
olution & mean distances
anets.

	PERIOD	MEAN DIST.
Hygeia	2,041 Days	288 Millions of Miles
Jupiter	4,332 "	475 "
Saturn	10,759 "	871 "
Uranus	30,687 "	1,752 "
Neptune	60,127 "	2,743 "

Orbit of Neptune

Uranus

Neptune

e Planets from the Sun.

A Q U A R I U S

C A P R I C O R N U S

S C O R P I O

S A G I T T A R I U S

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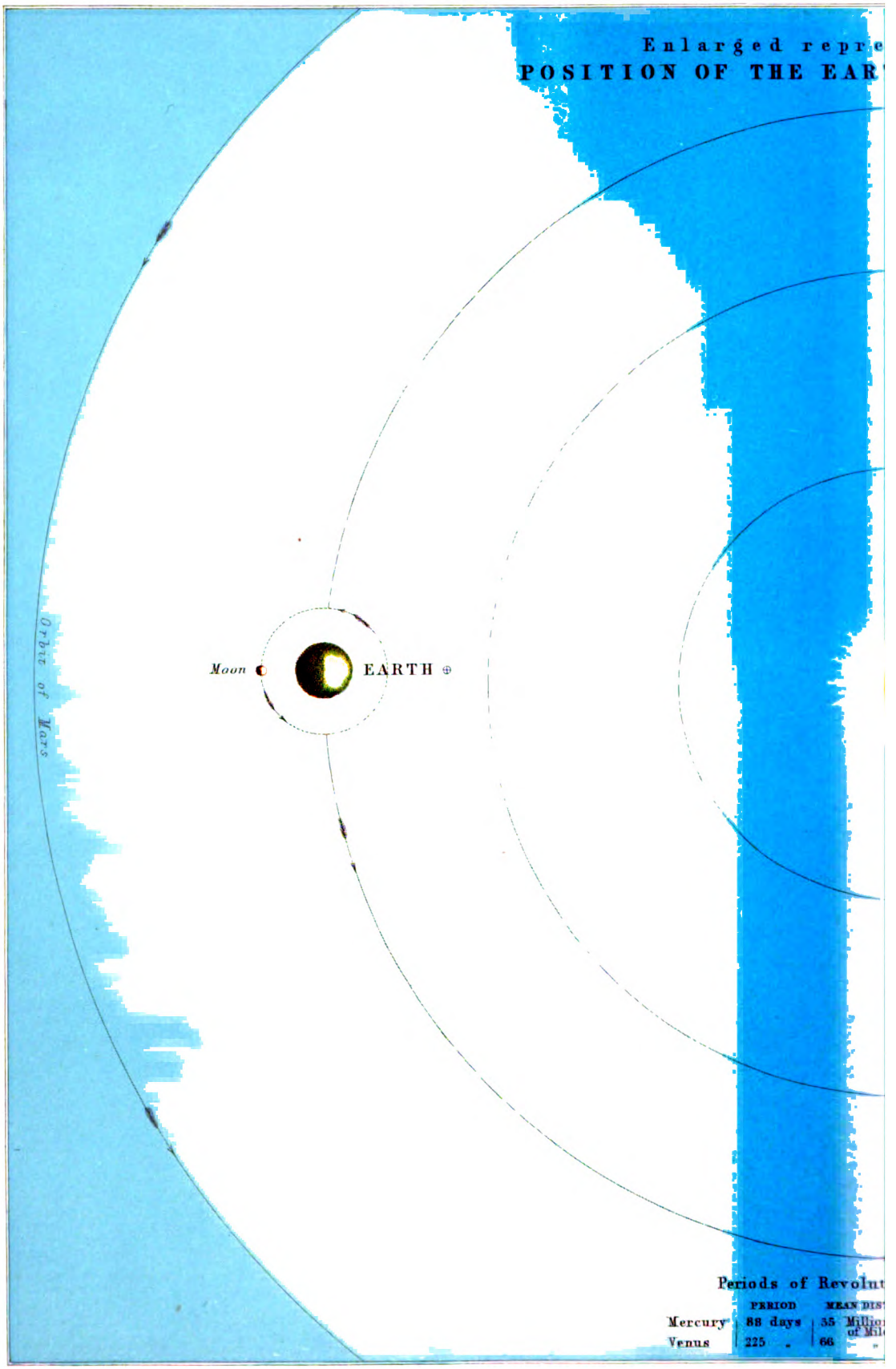

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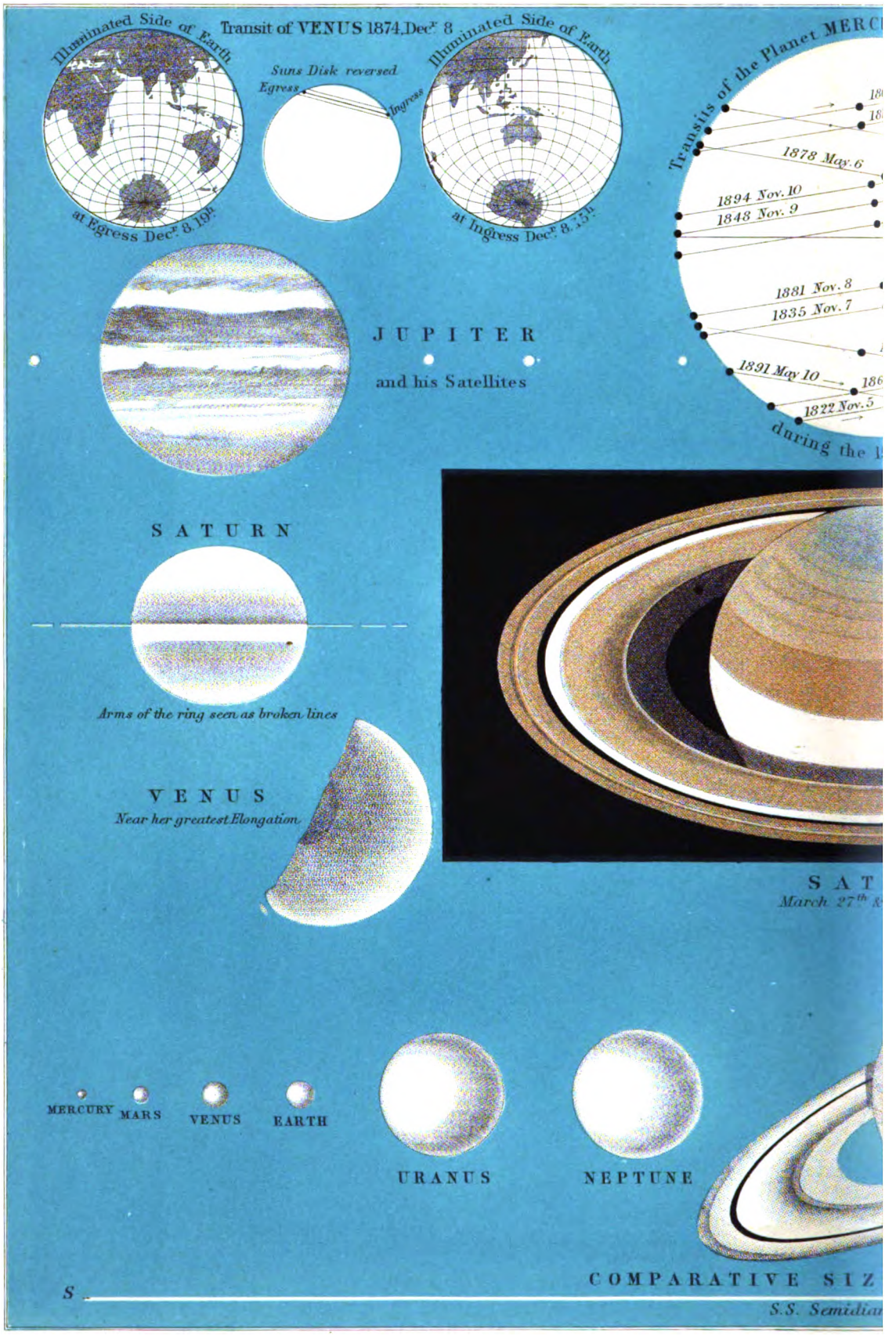

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URY across the disc of the Sun

61 Nov. 12
15 Nov. 12
1832 May 5
1802 Nov. 9
Ecliptic
1845 May 8
8 Nov. 5
9th Century.

Transit of VENUS 1882. Dec.r 6.

Illuminated Side of Earth at Egress Dec.r 6. 8h

Suns Disk reversed

Egress

Ingress

Illuminated Side of Earth at Ingress Dec.r 6. 2h

JUPITER
With the Shadow of a Satellite crossing his disc

MARS
April 20th 1856

VENUS
As drawn by Schroter

URN
29th 1856

SATURN

JUPITER

ES OF THE PLANETS

S

eter of the Sun.

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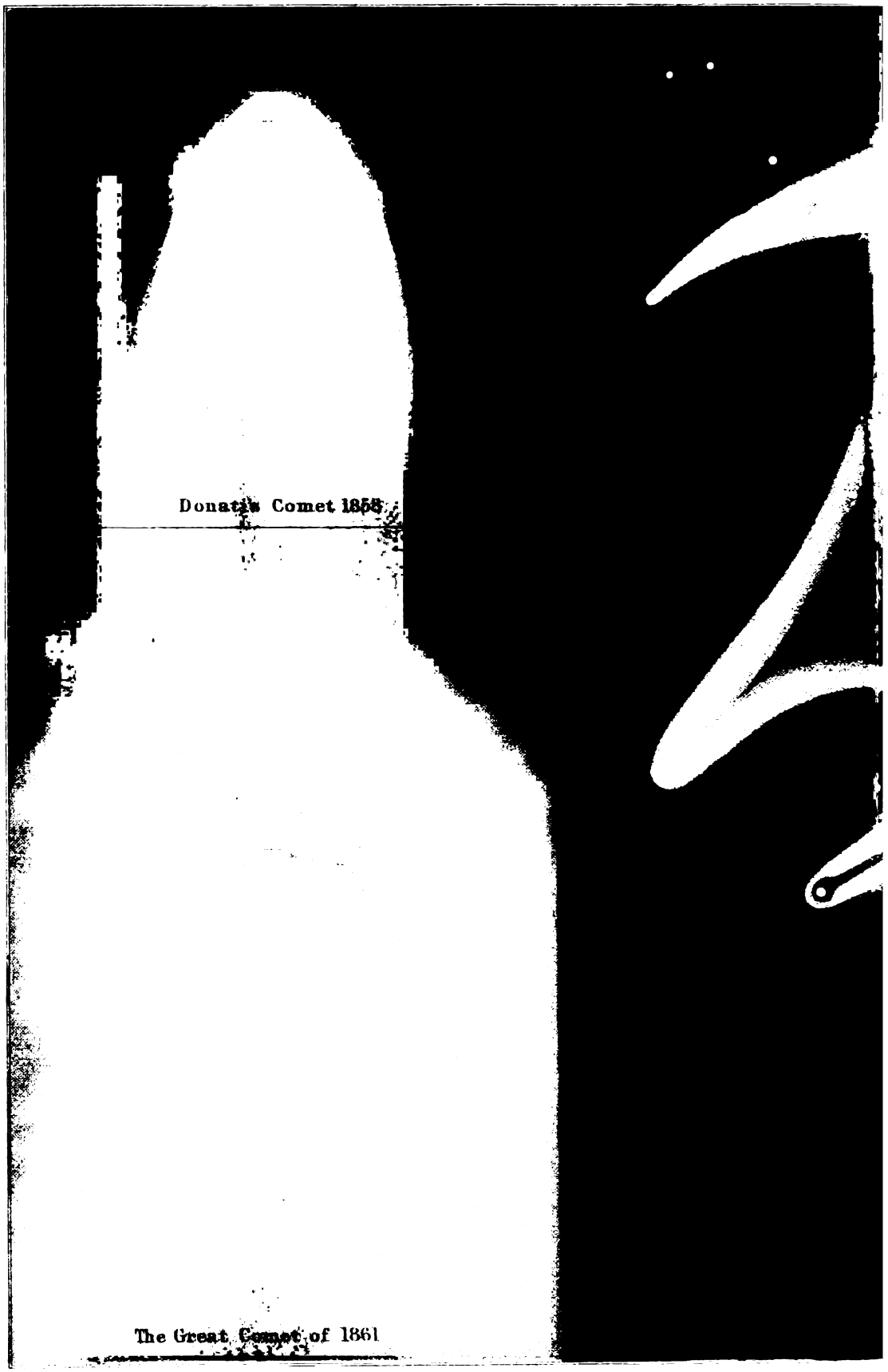
ns. Edinburgh & London.



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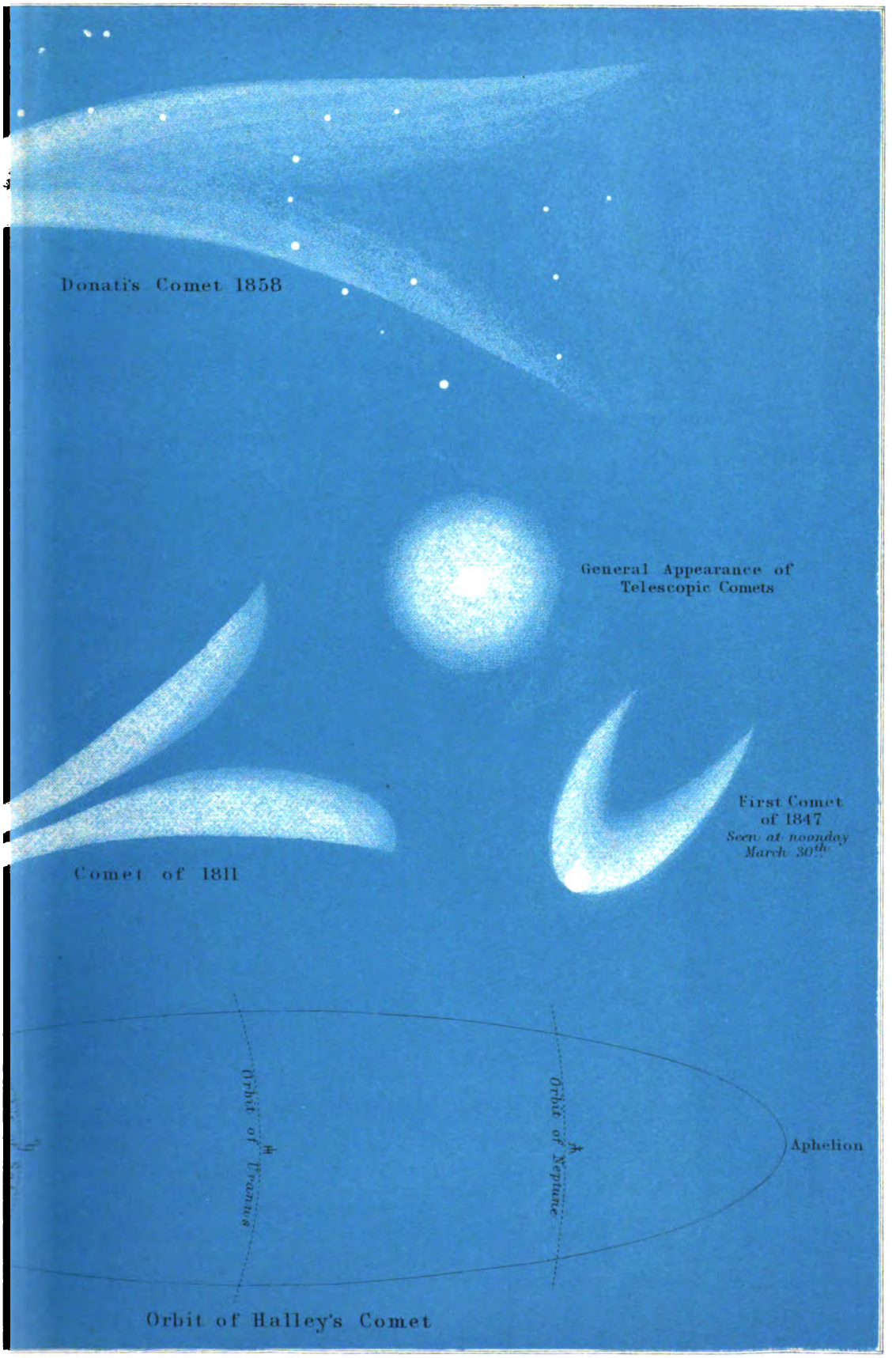

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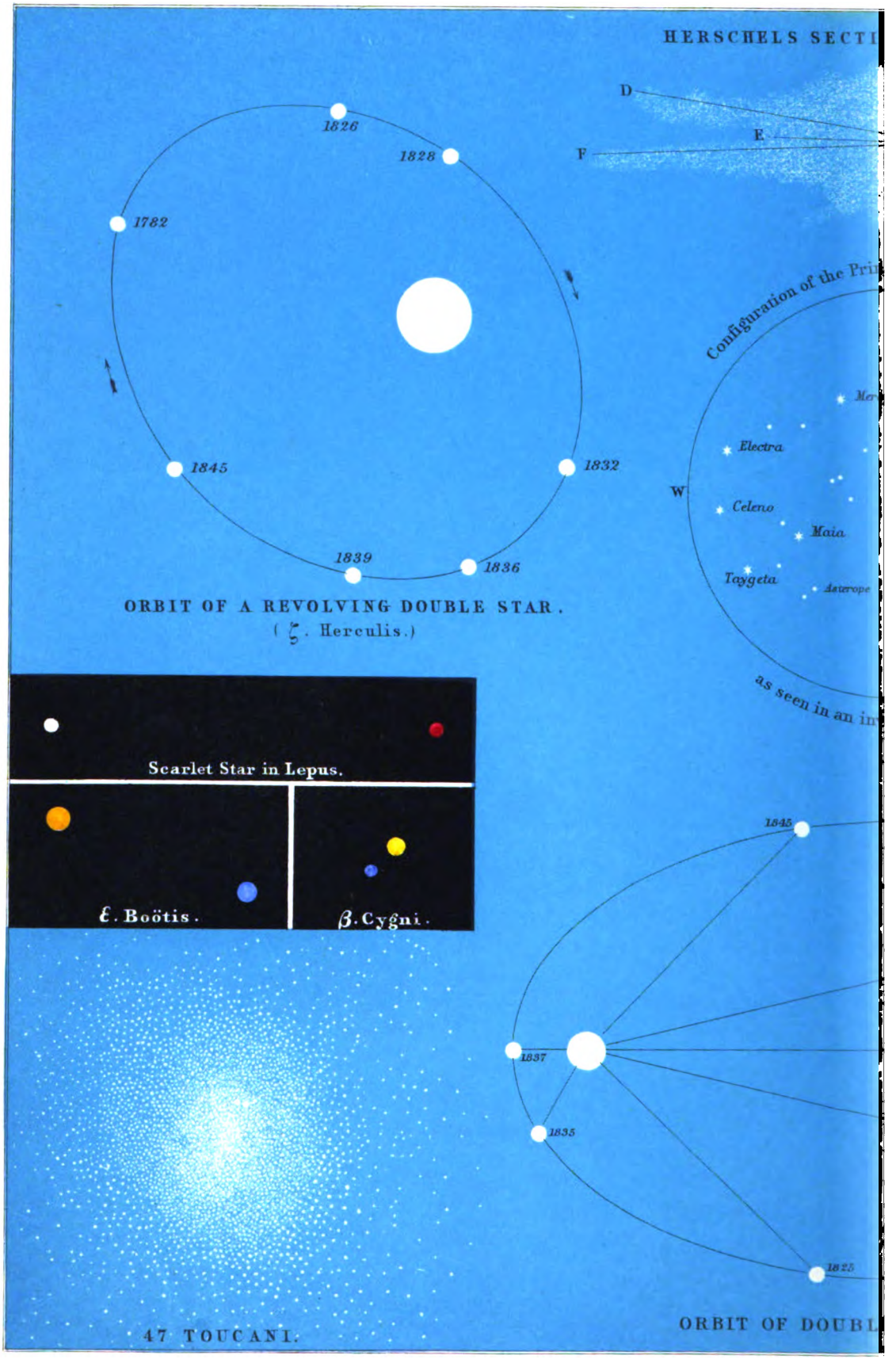

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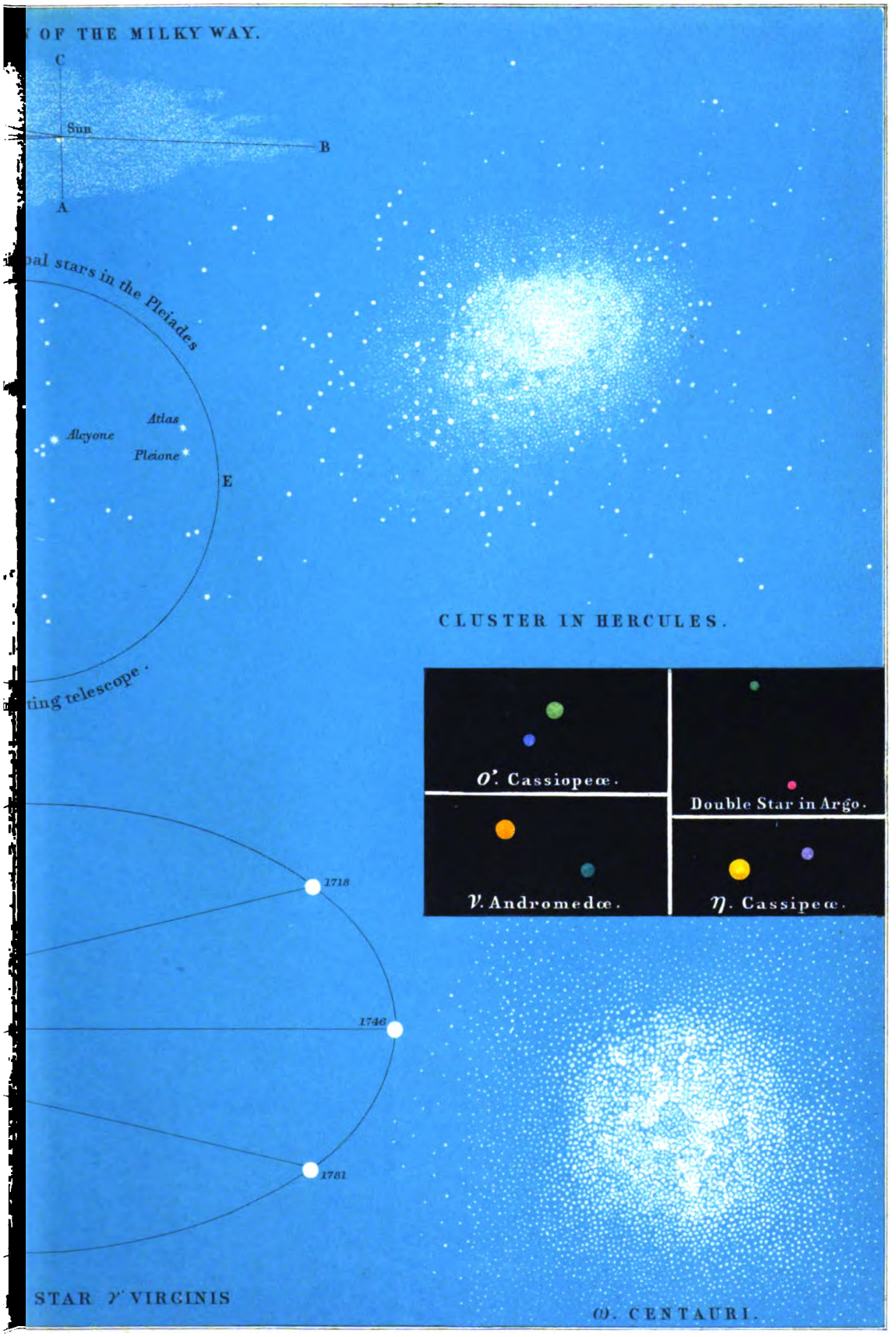

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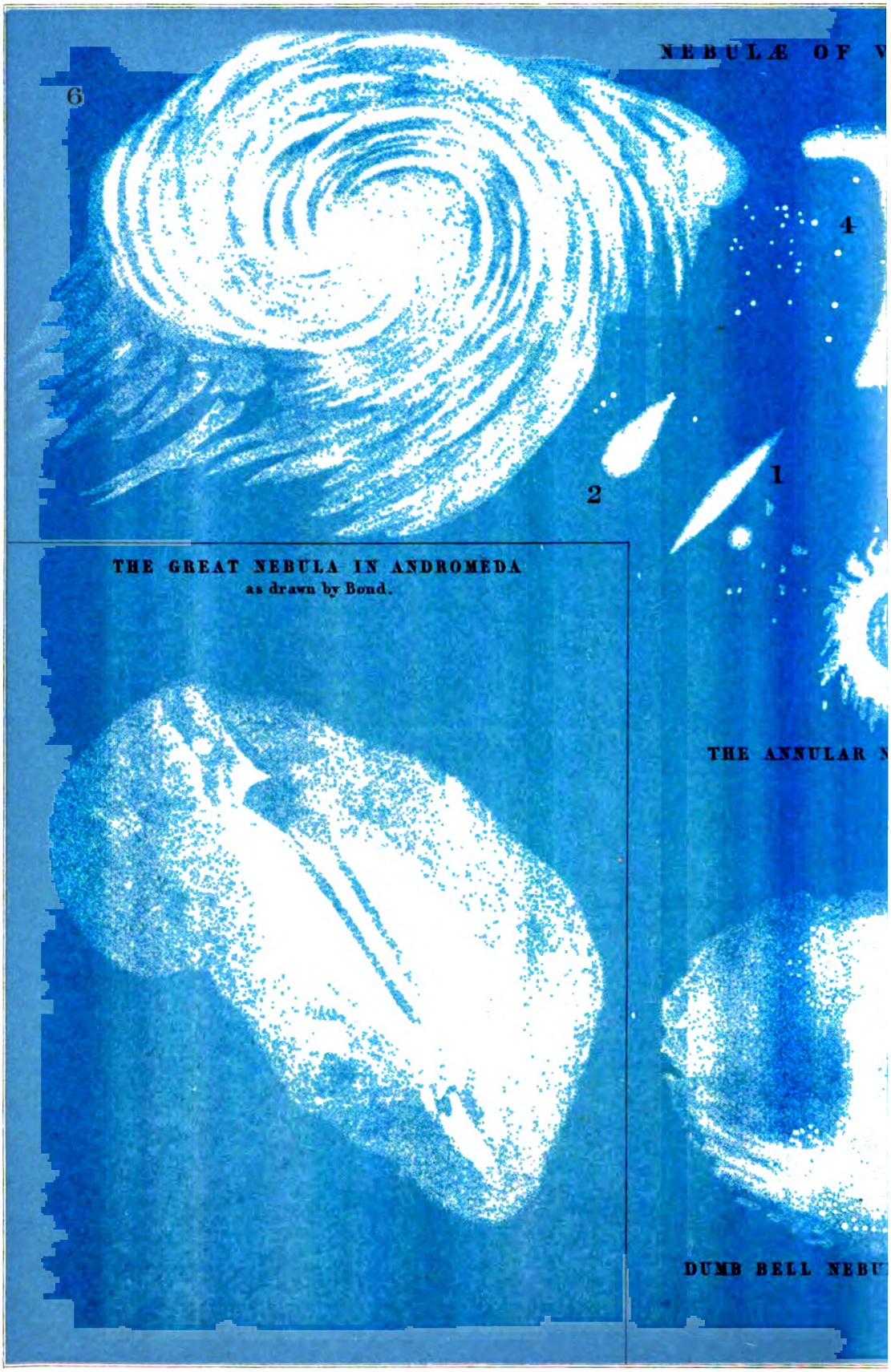

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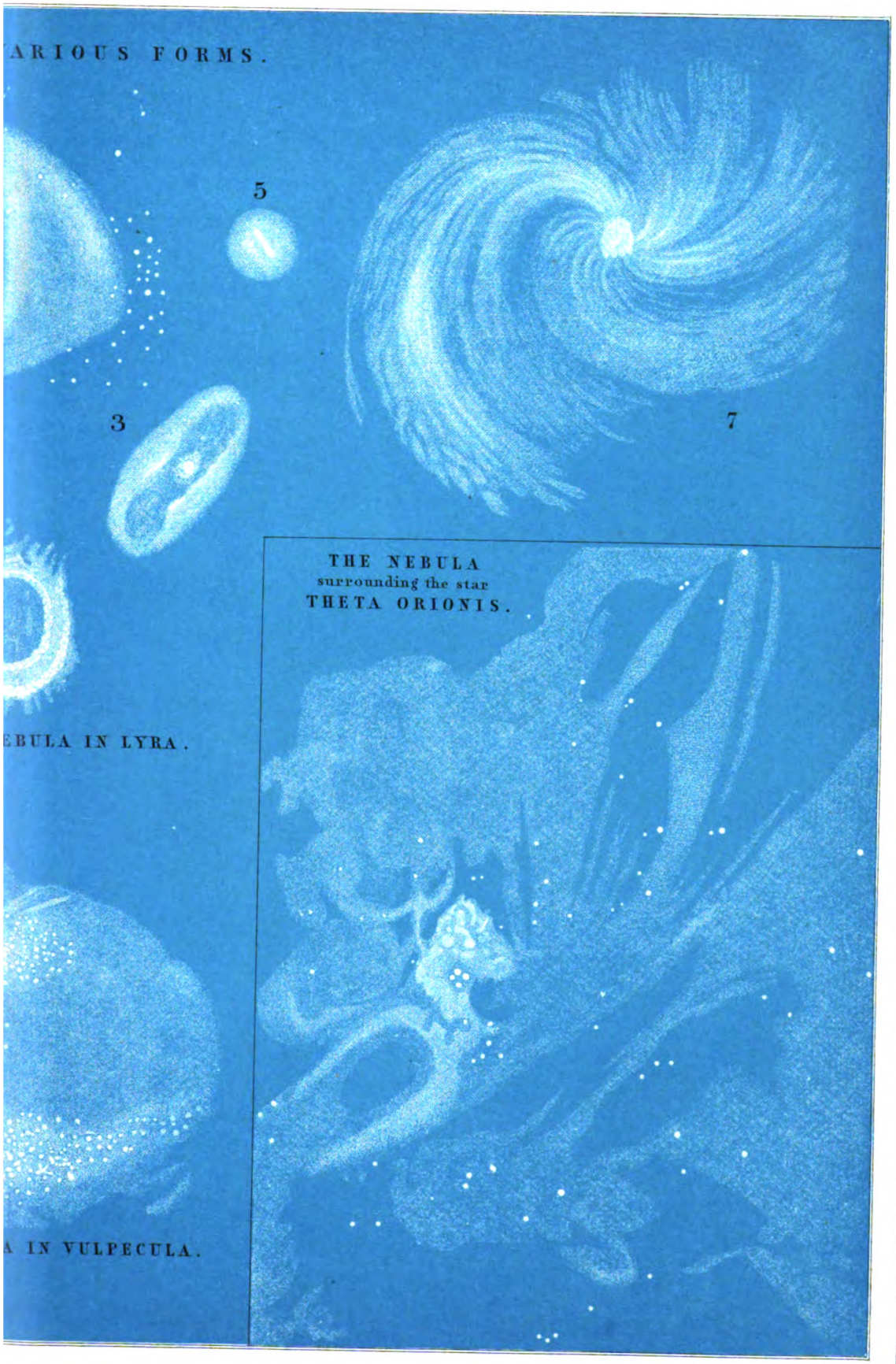

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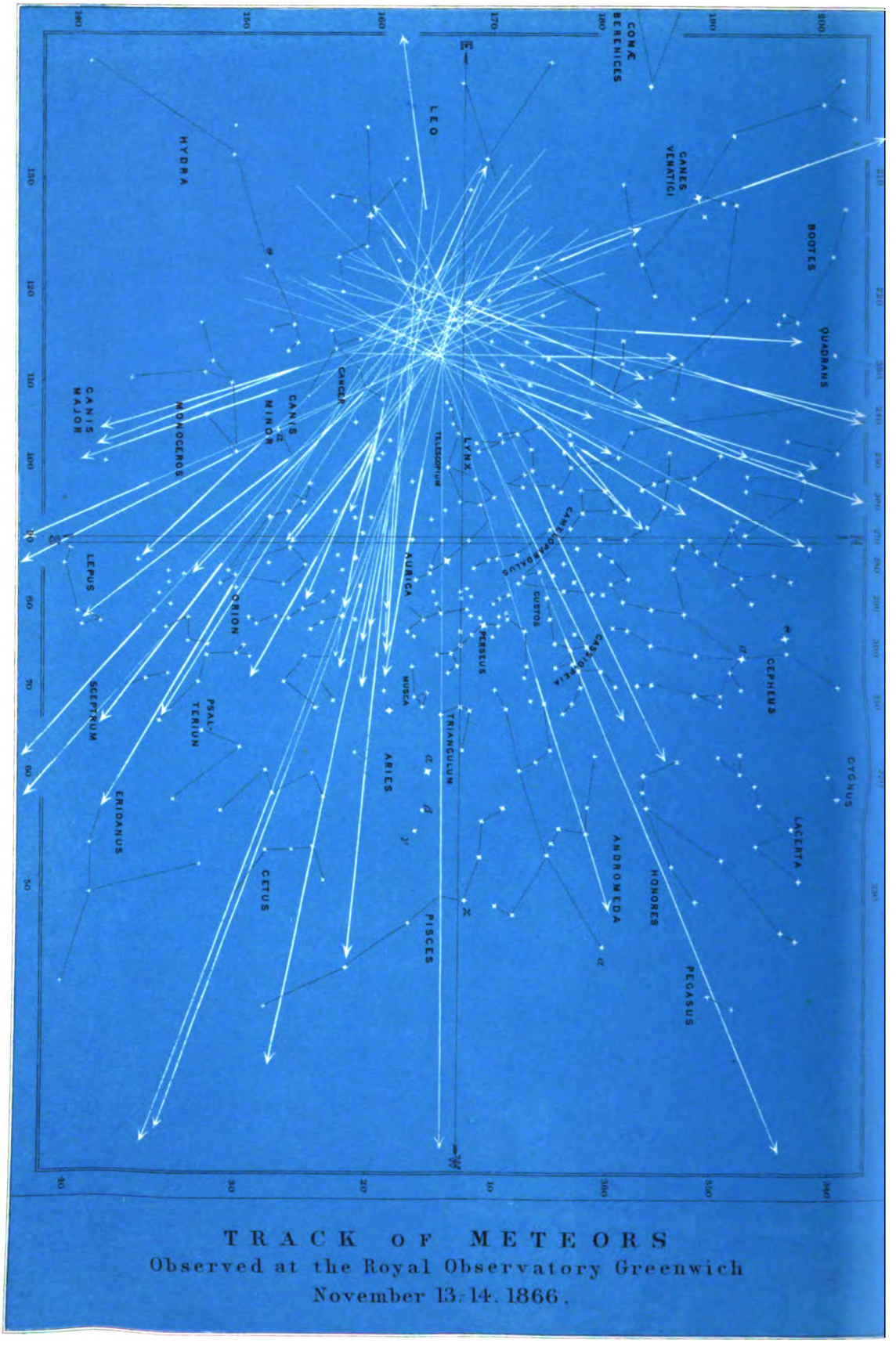

TRACK OF METEORS

Observed at the Royal Observatory Greenwich

November 13-14. 1866.

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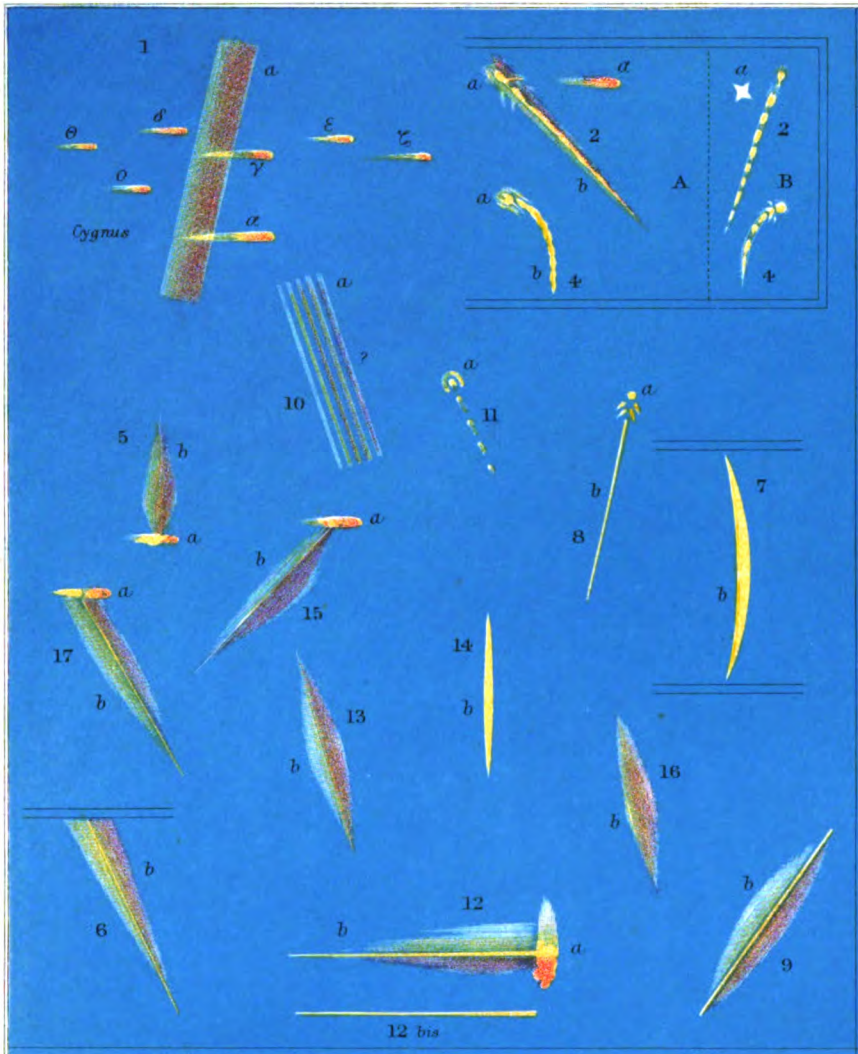
PLATE 13.



Prismatic Spectra of the August Meteors, 1866.
Observed by Mr A. S. Herschel

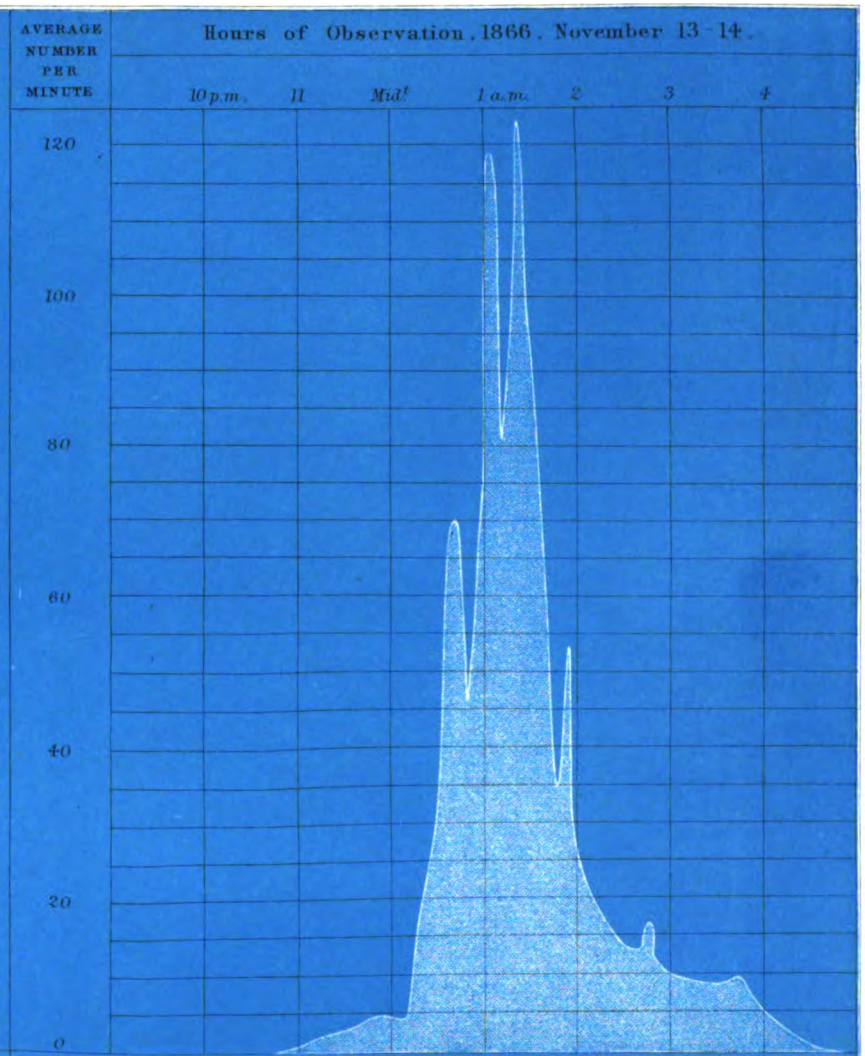


Diagram showing the Average Number of Meteors per Minute
Observed at the Royal Observatory Greenwich

Engr by W & A K Johnston Edinburgh

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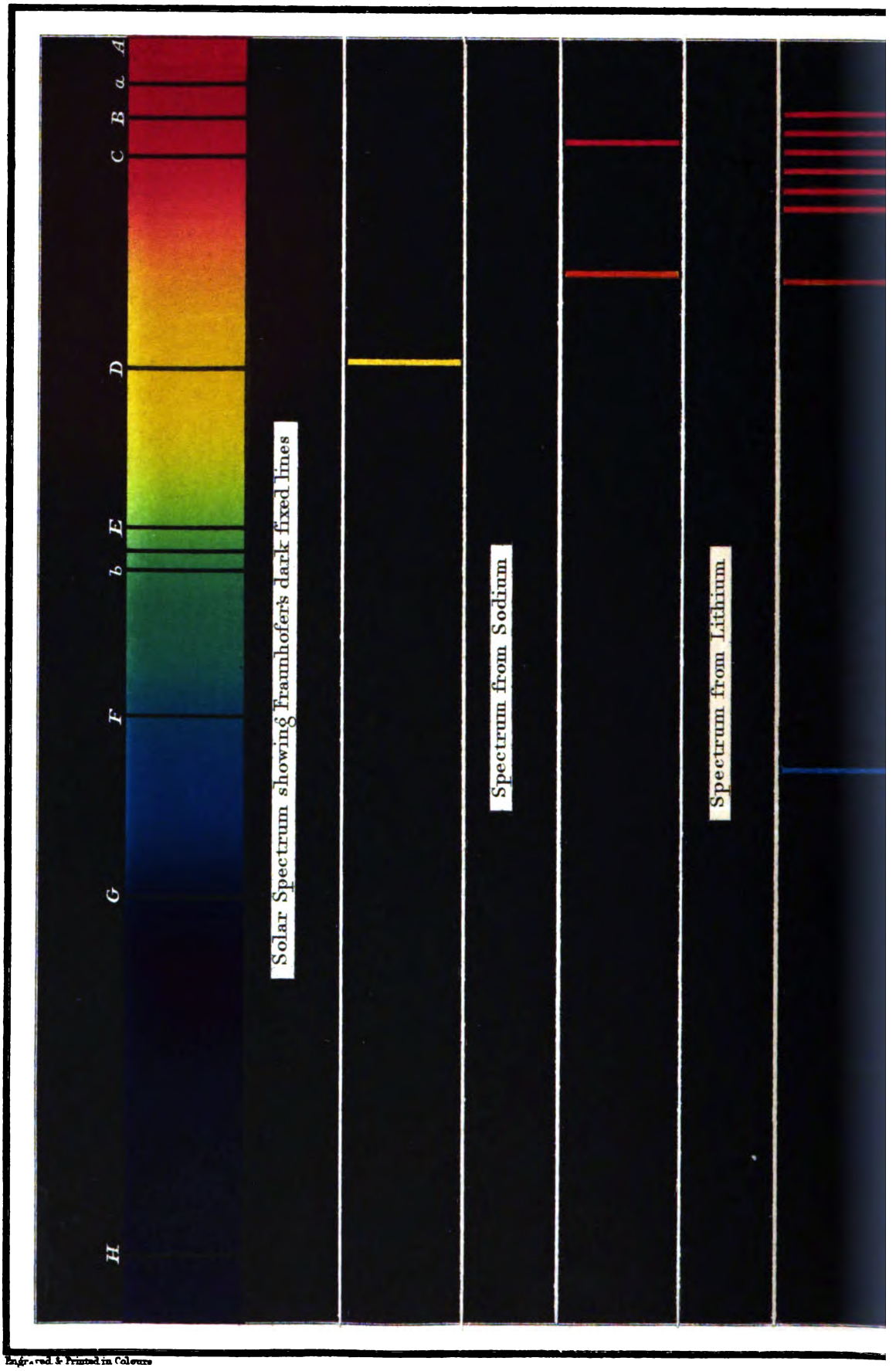

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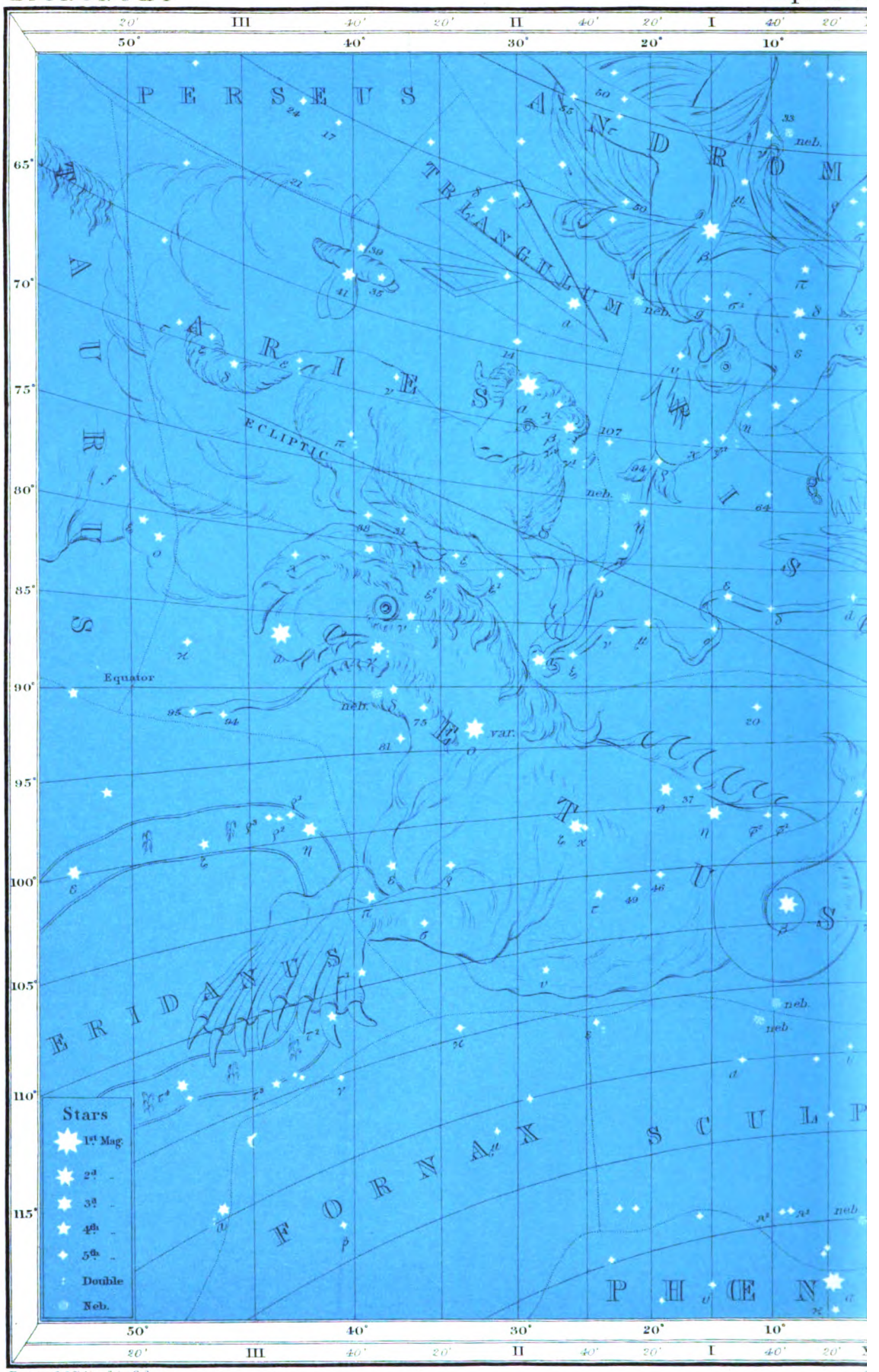

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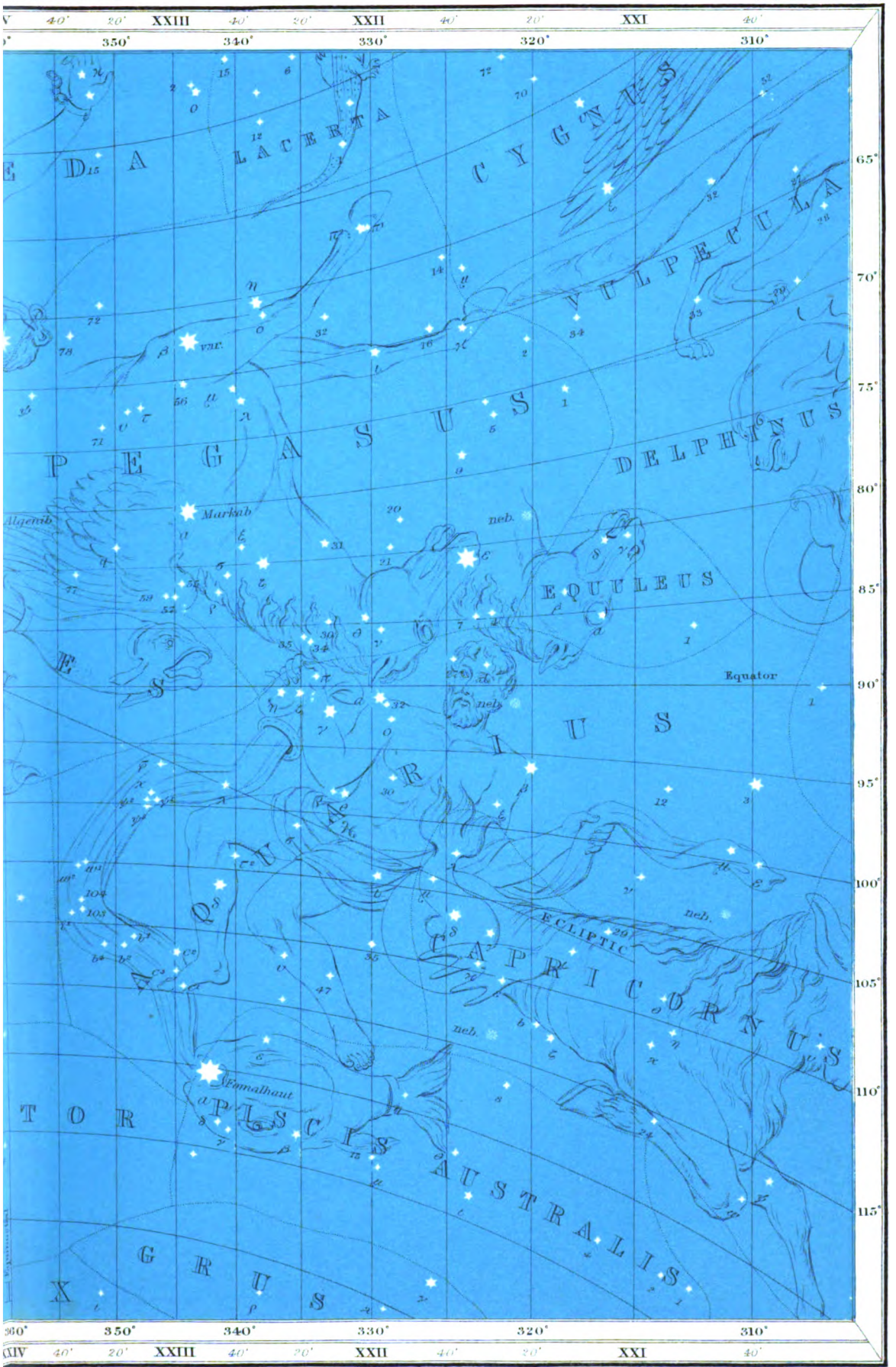

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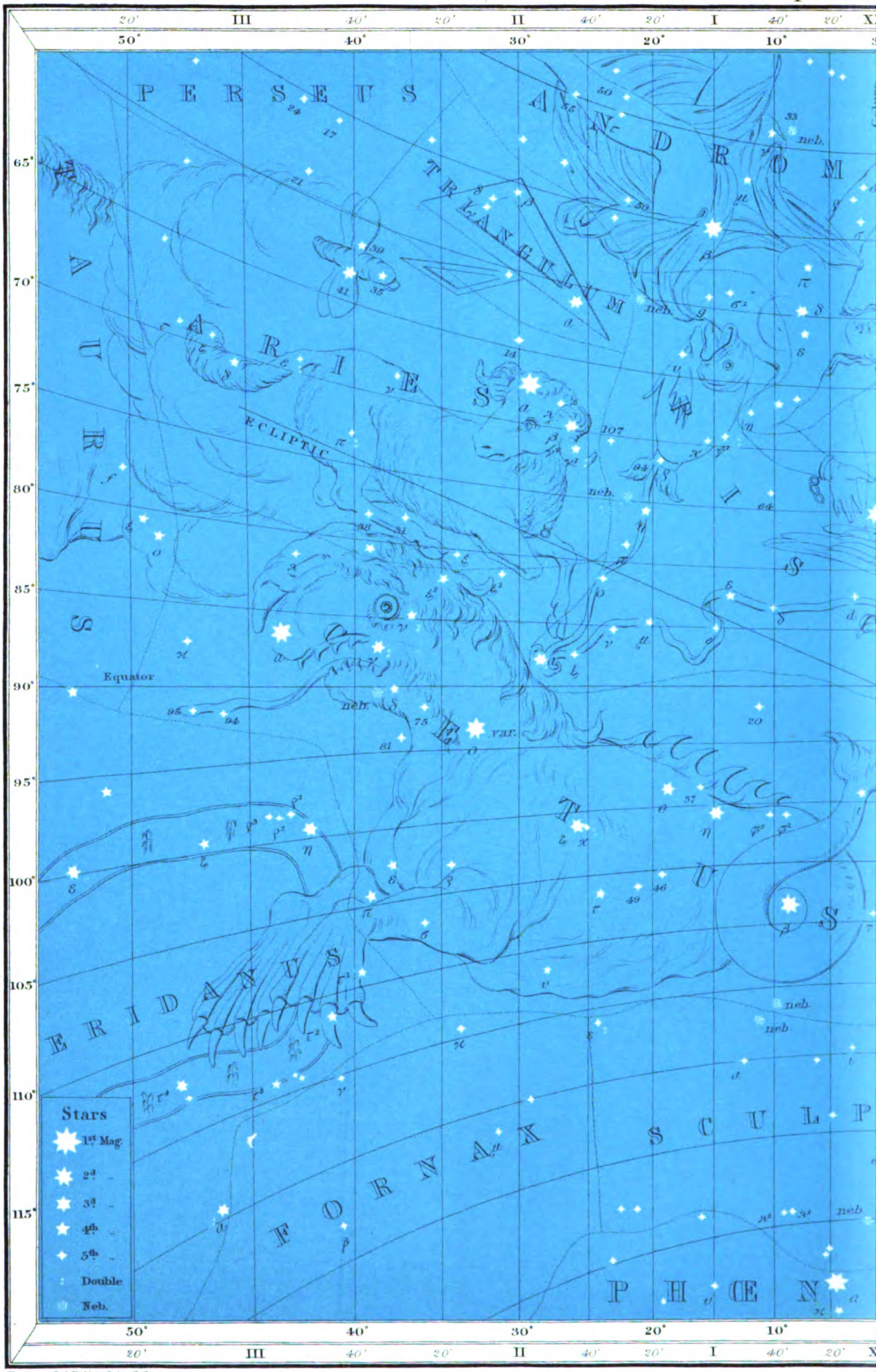
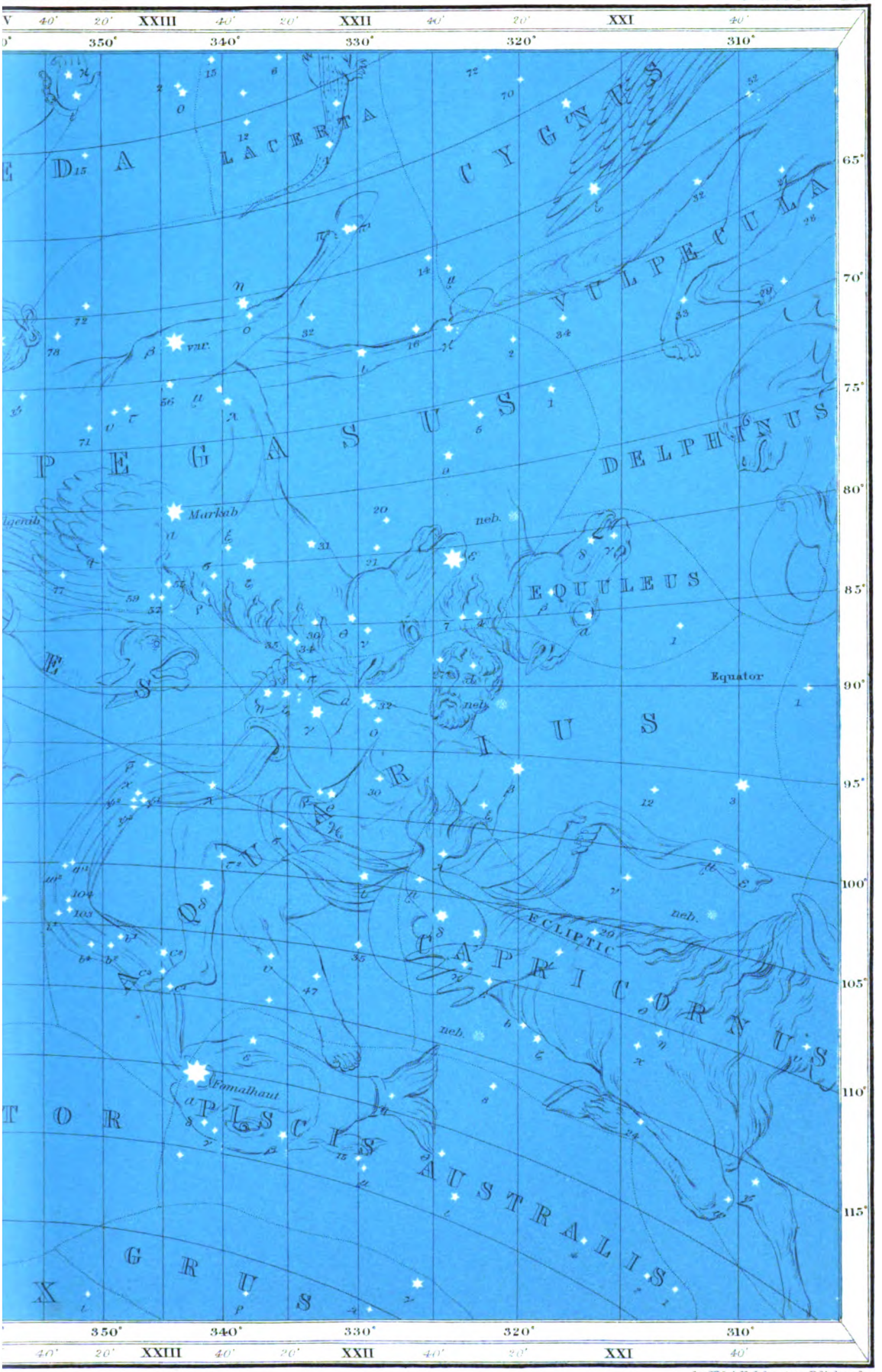

PERSEUS
ANDROM
TRIANGULUM
ARIES
AURIGA
ECLIPTIC
Equator
ERIDANUS
FORNAX
SCULP
PHOEN
neb.
var.
Stars
1st Mag.
2d
3d
4th
5th
Double
Neb.



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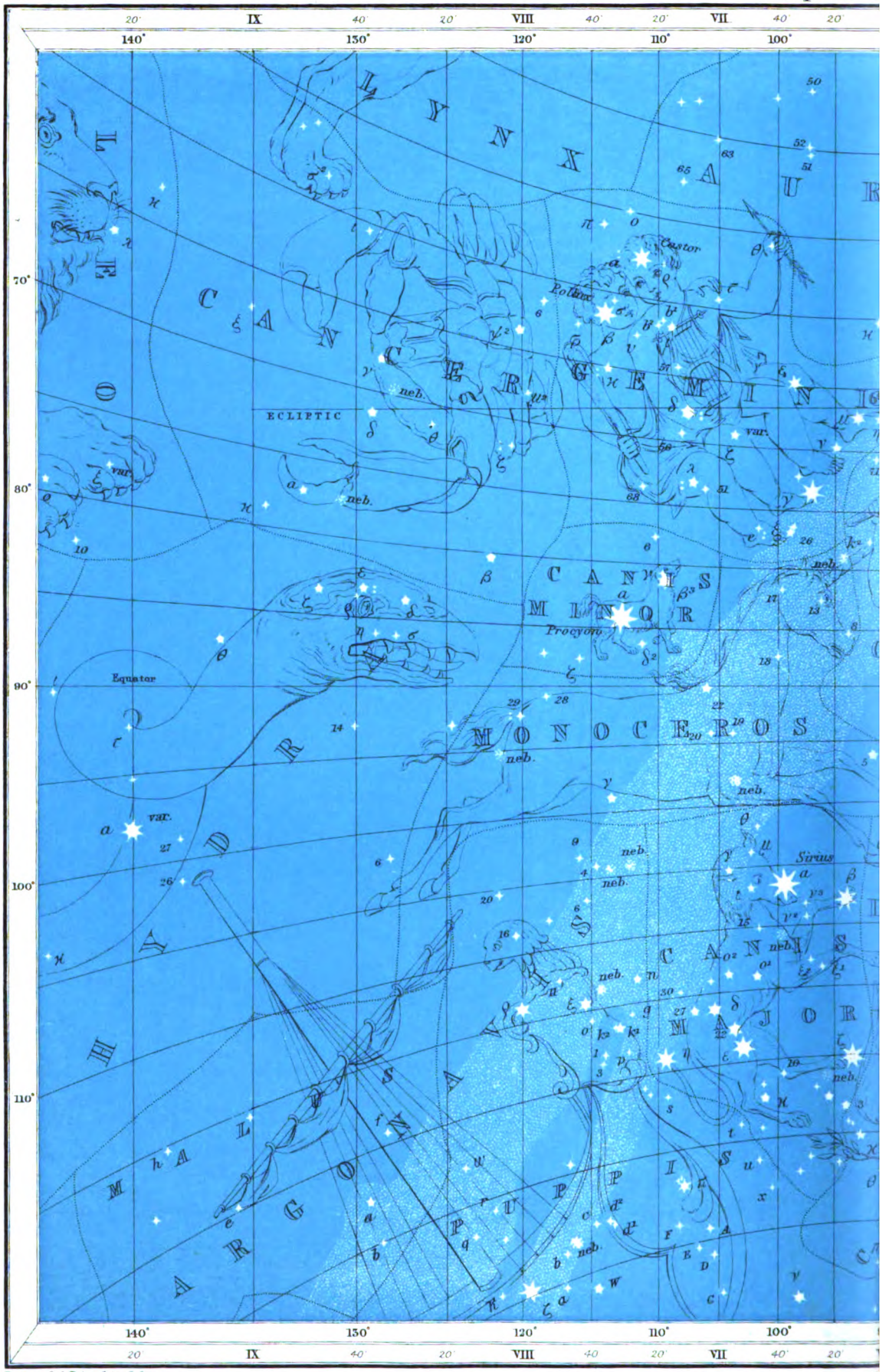

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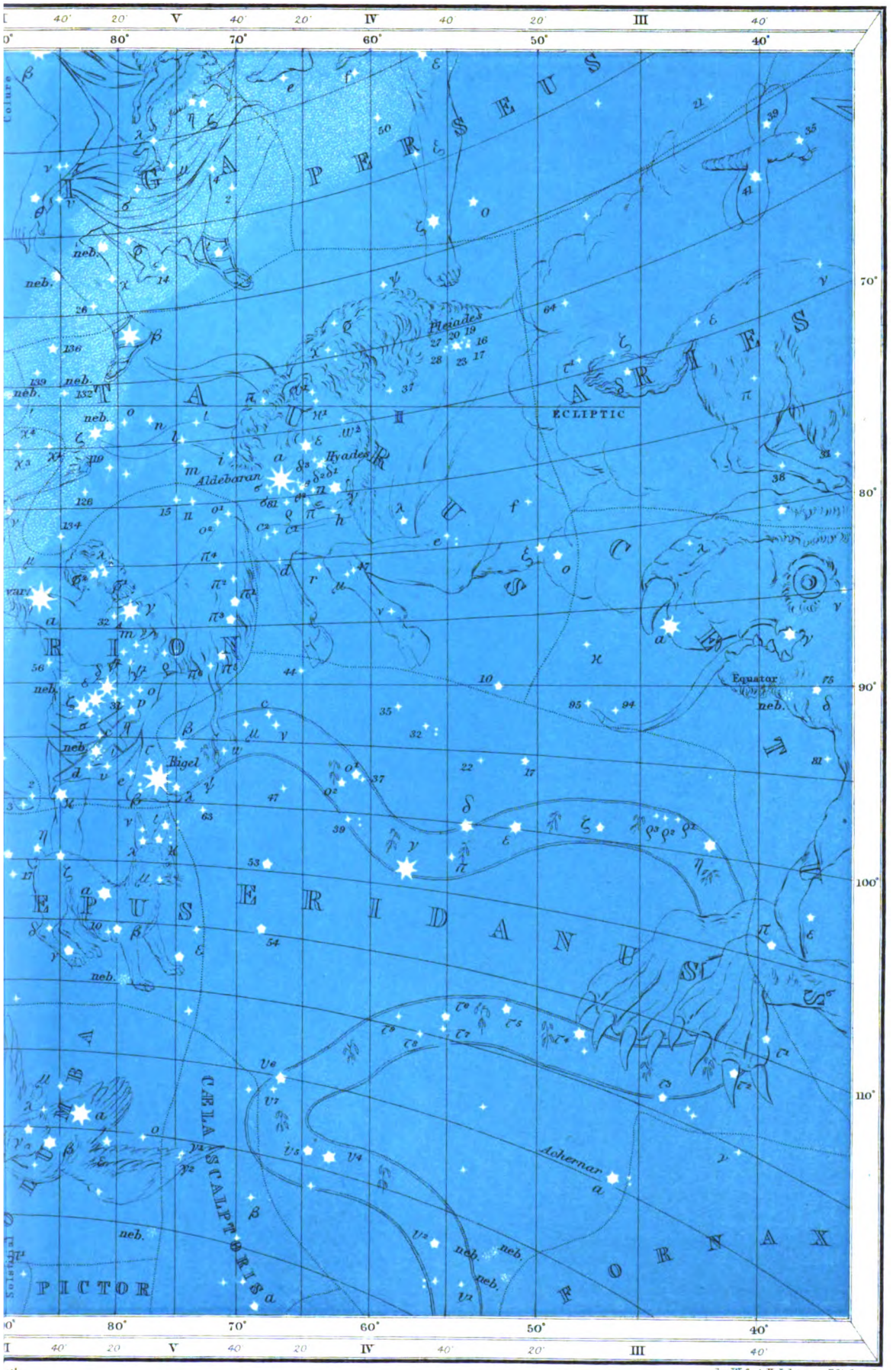

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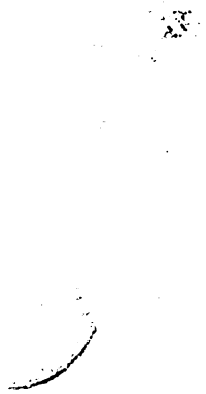
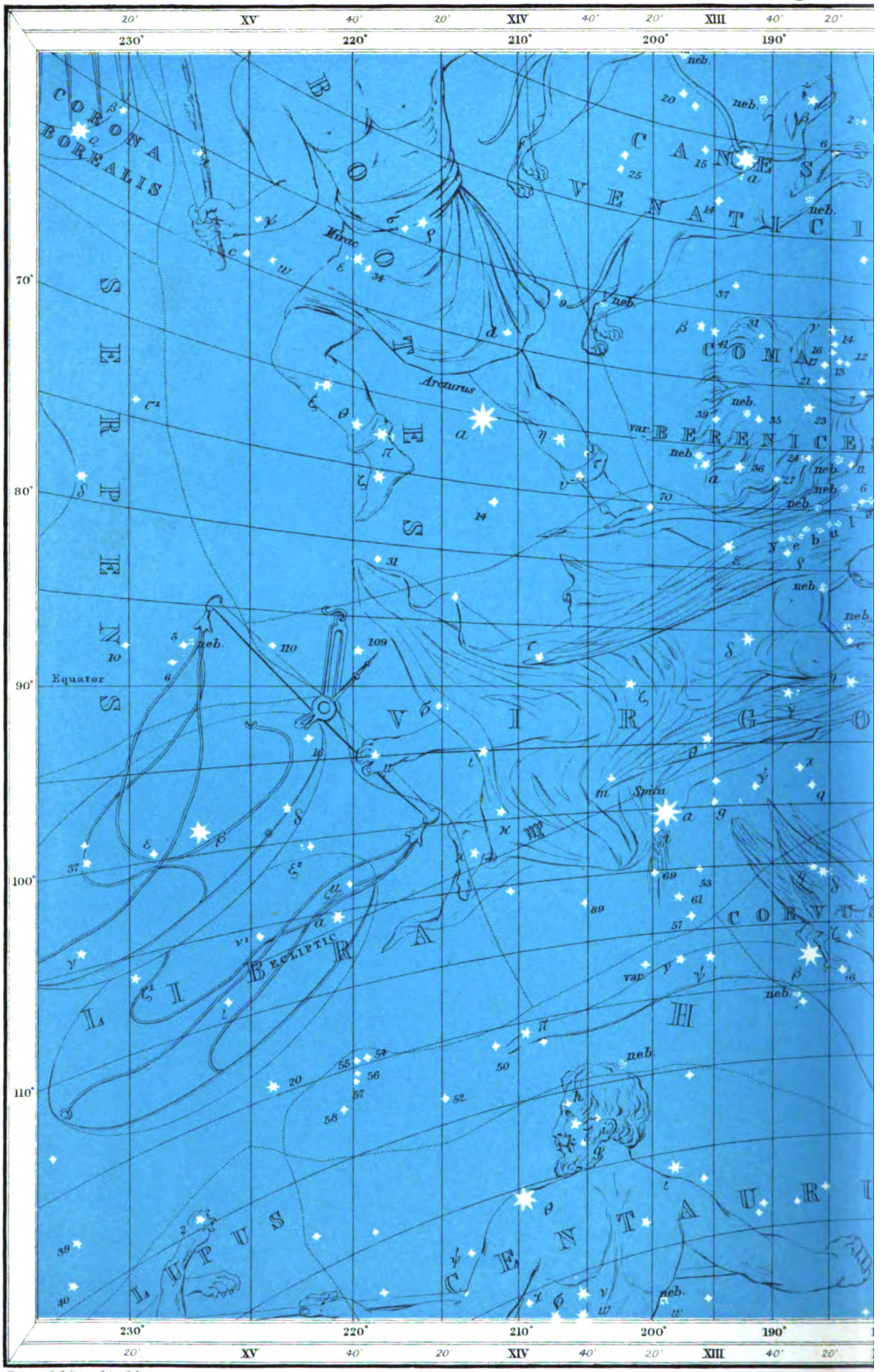
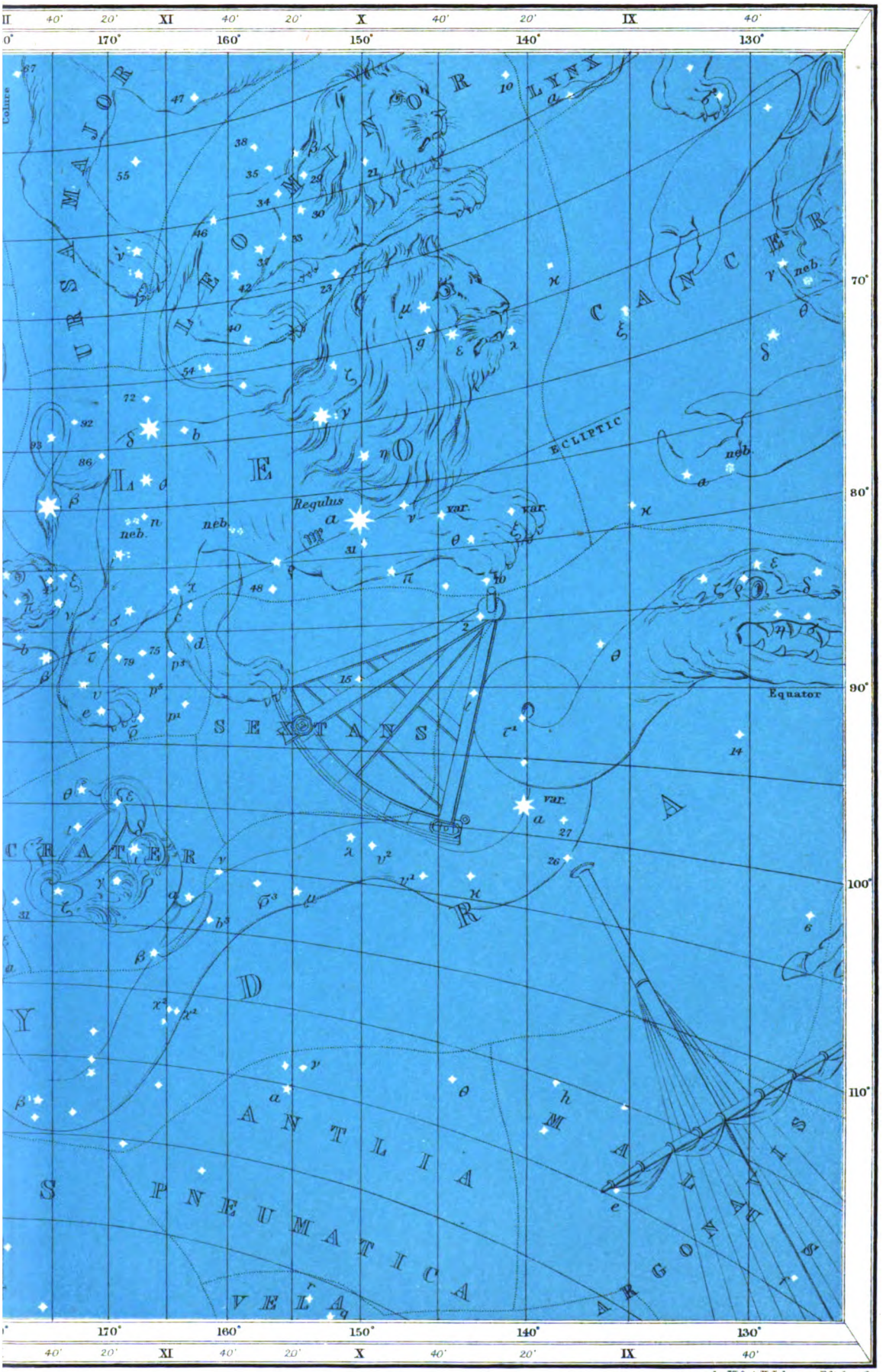



20' XV 40' 20' XIV 40' 20' XIII 40' 20'
230° 220° 210° 200° 190°
70° 80° 90° 100° 110°
CORONA BOREALIS
BOOTES
SERPENS
Mirac
Arcturus
CANES VENATICI
COMA BERENICE
var.
neb.
Equator
ECLIPTIC
Spica
CORVUS
HYDRA
LUPUS
CENTAURUS
230° 220° 210° 200° 190°
20' XV 40' 20' XIV 40' 20' XIII 40' 20'



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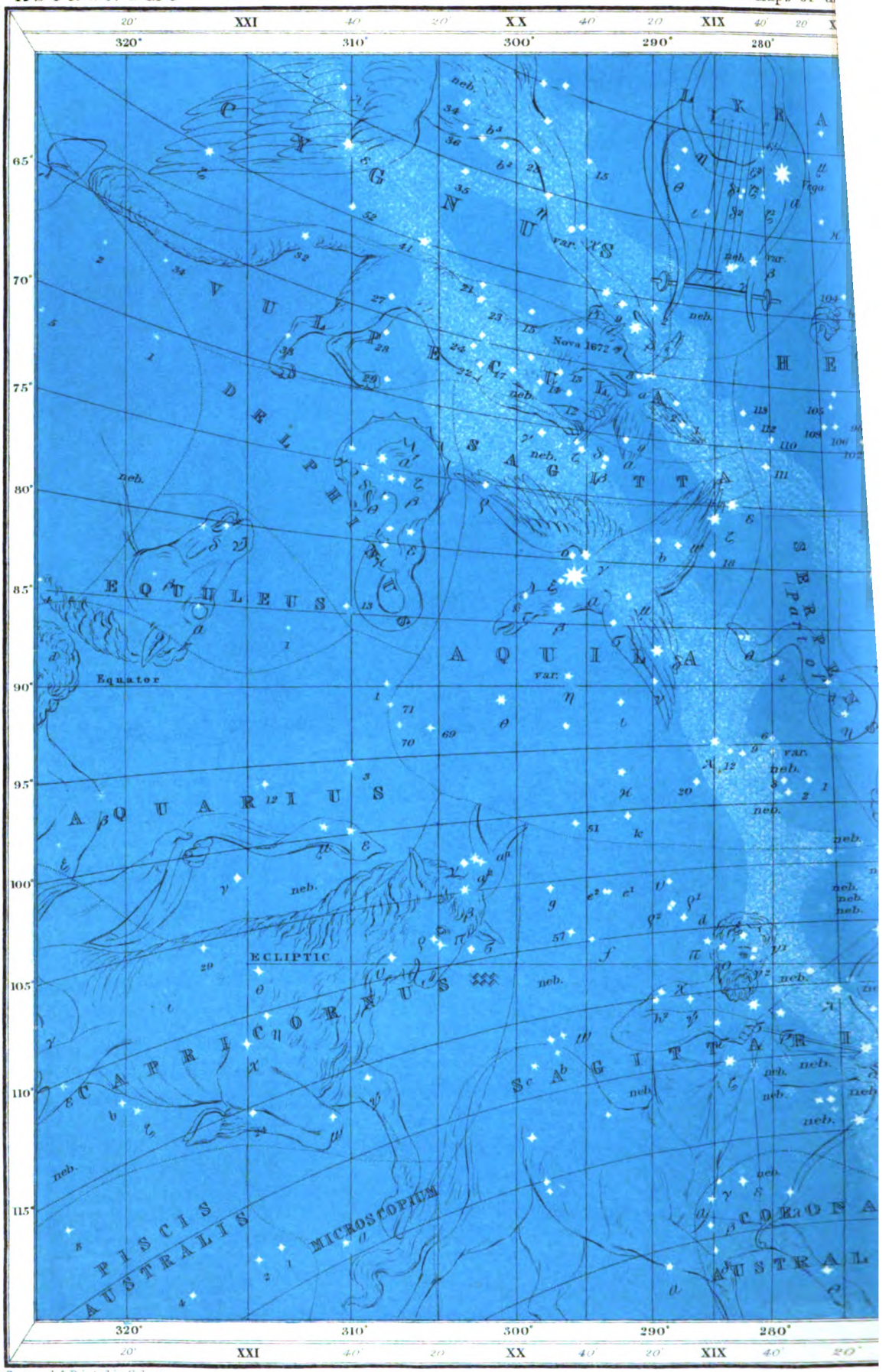

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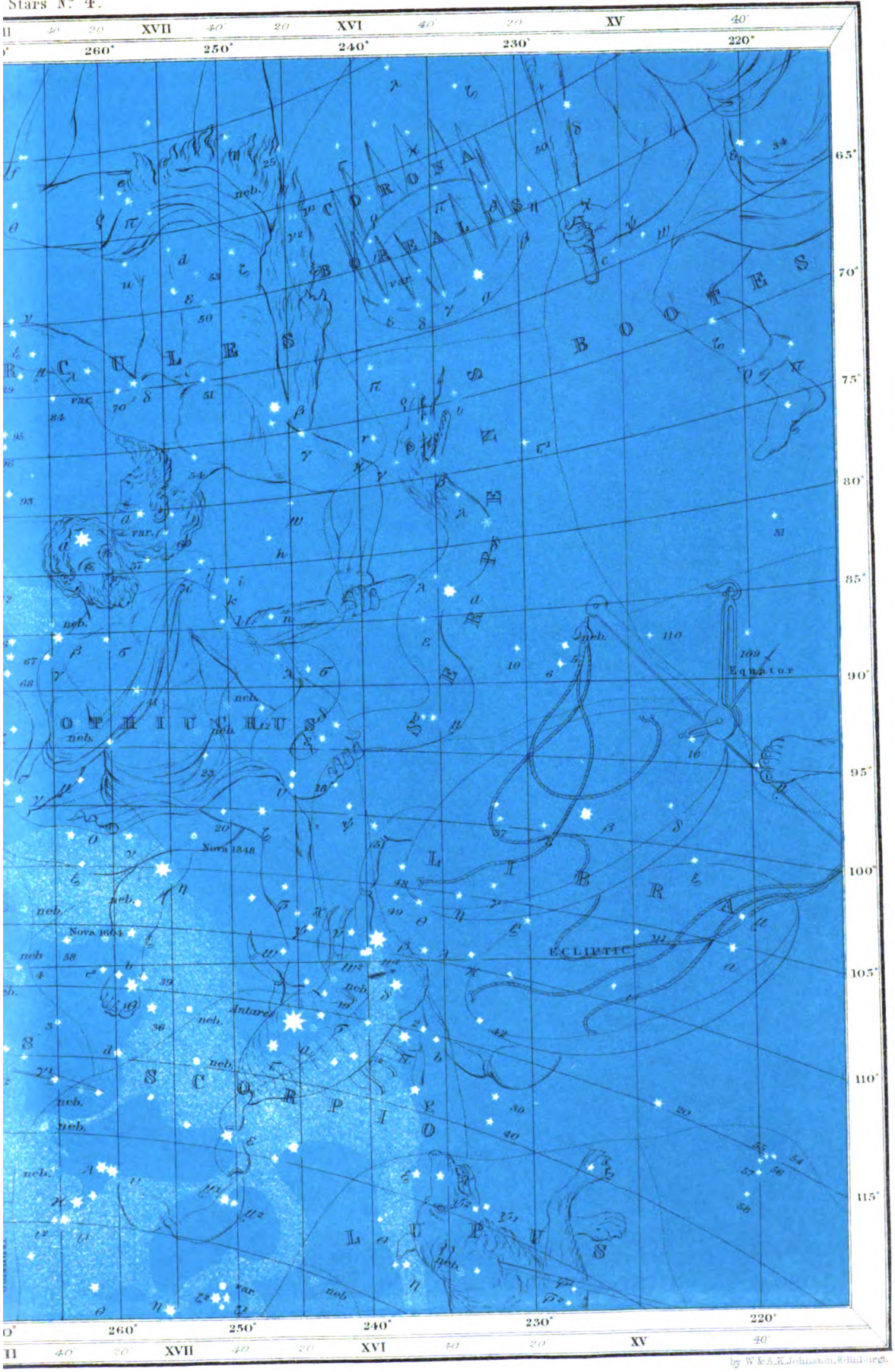

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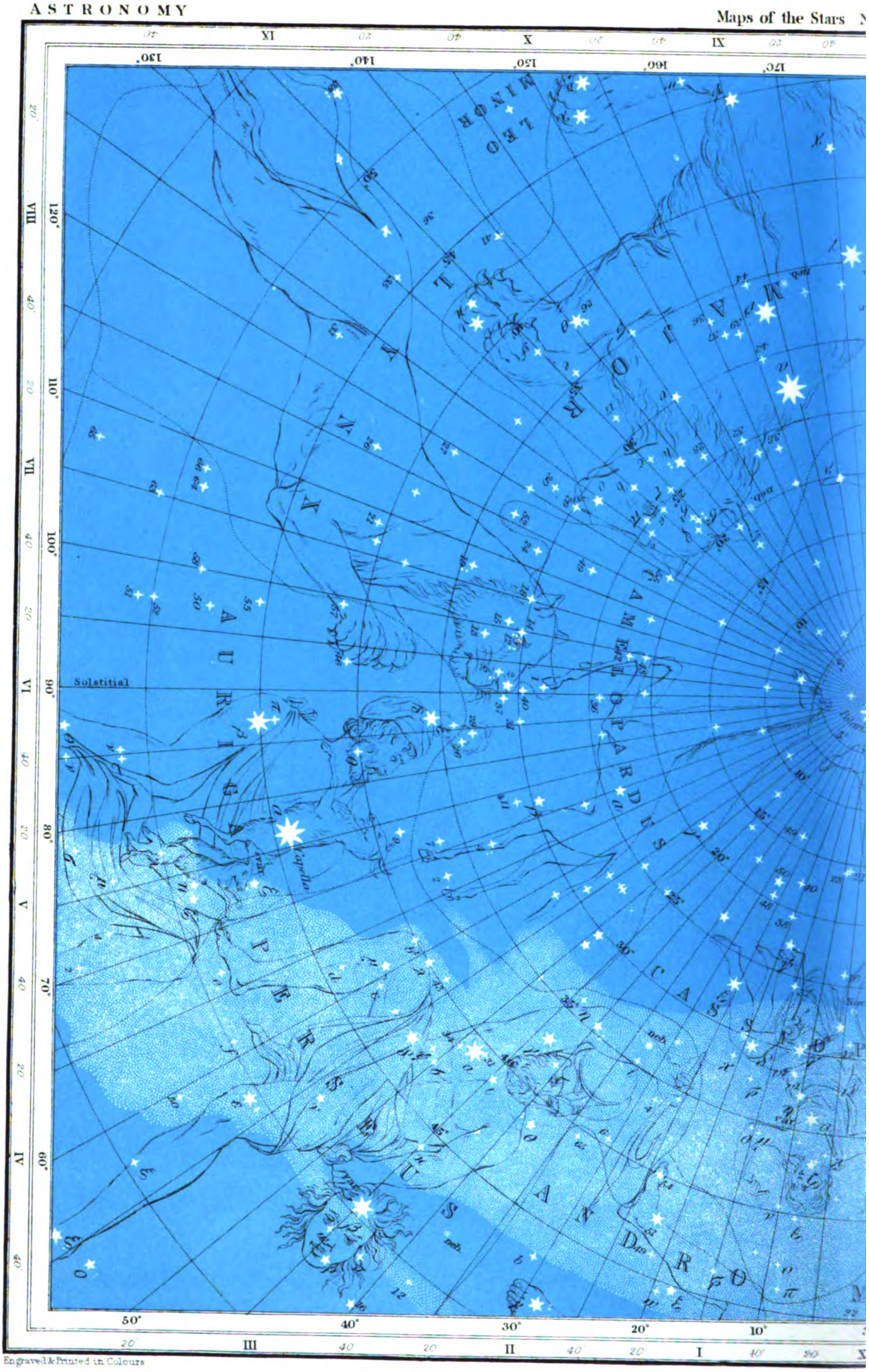

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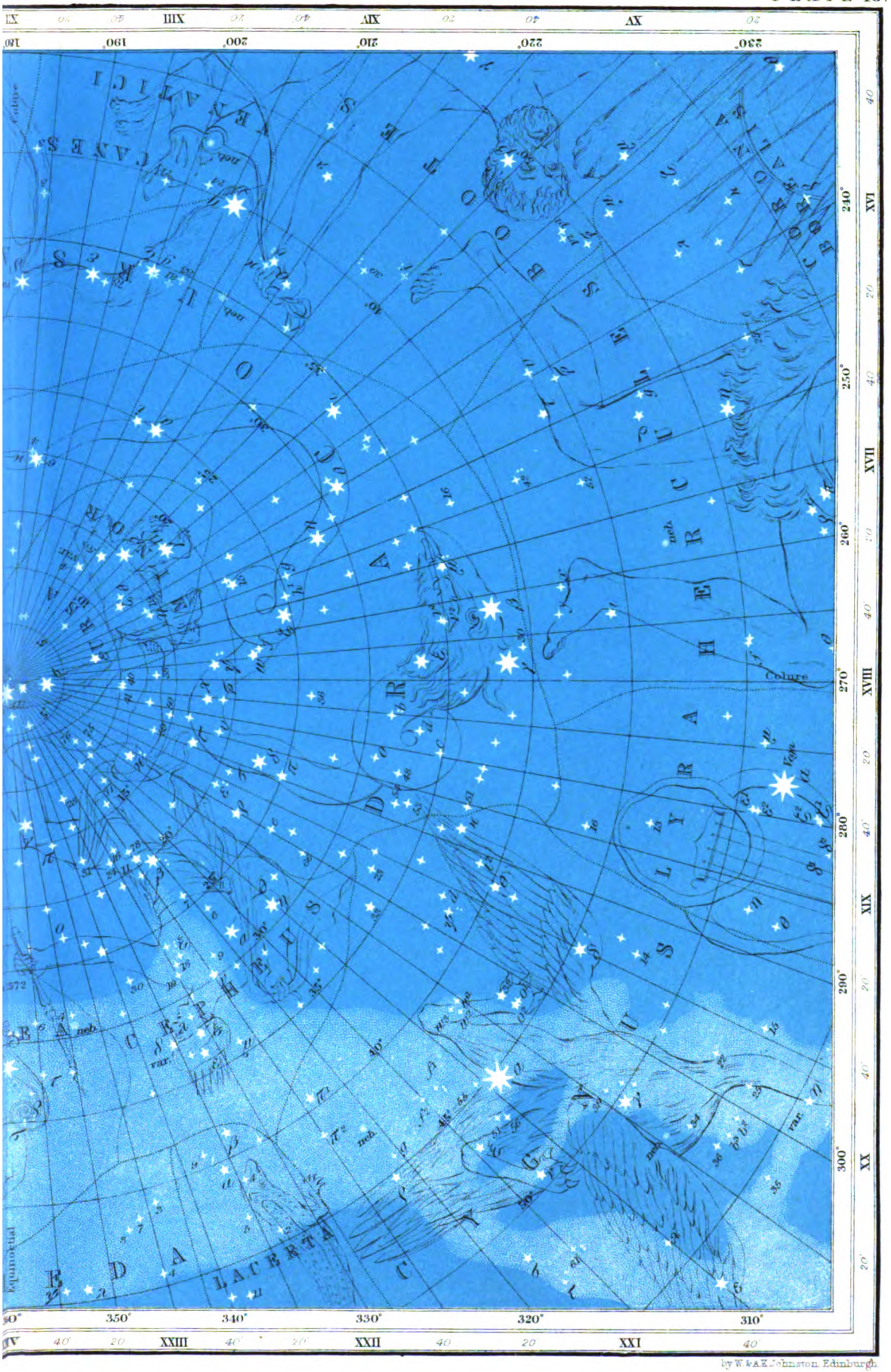

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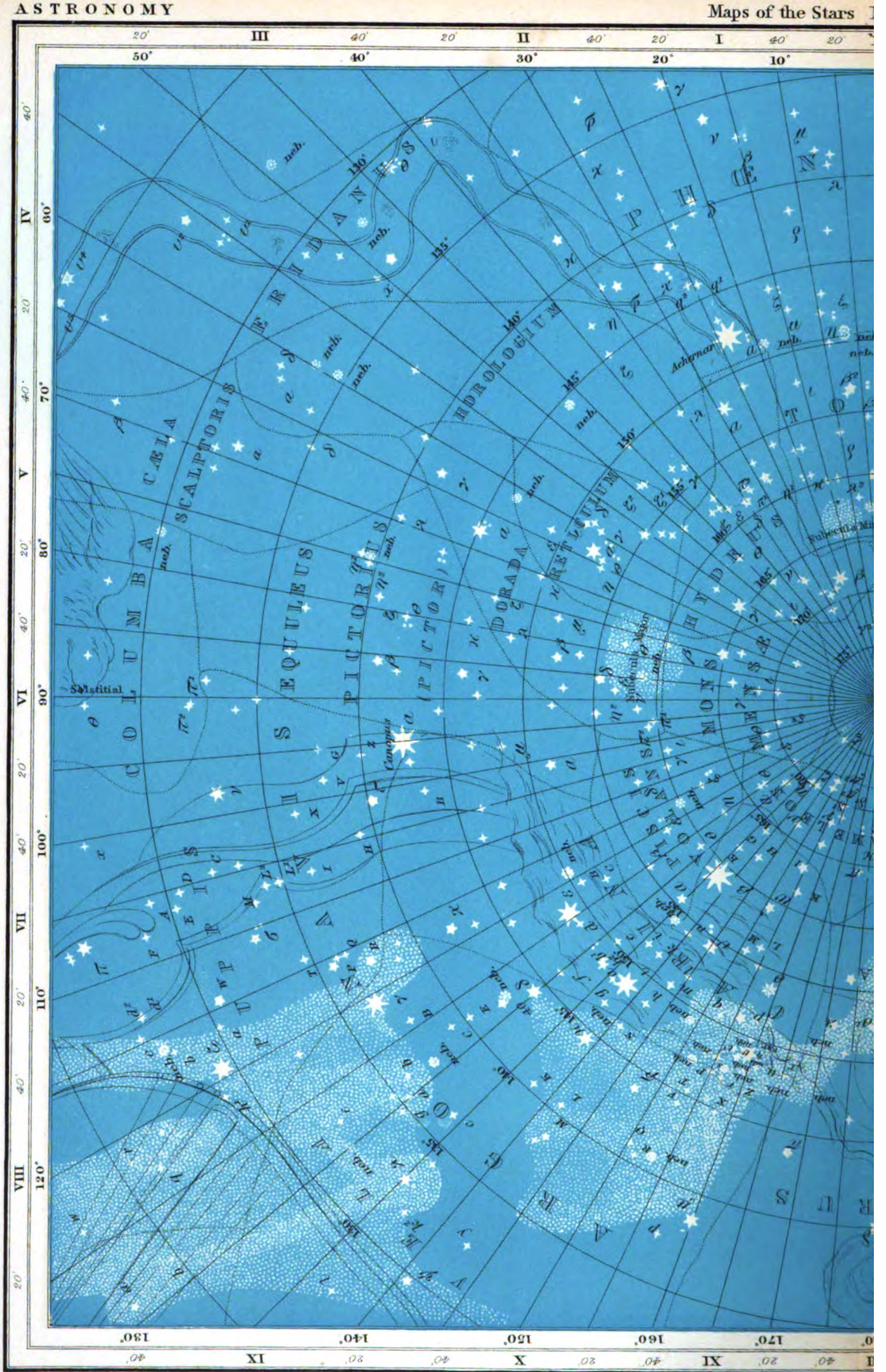

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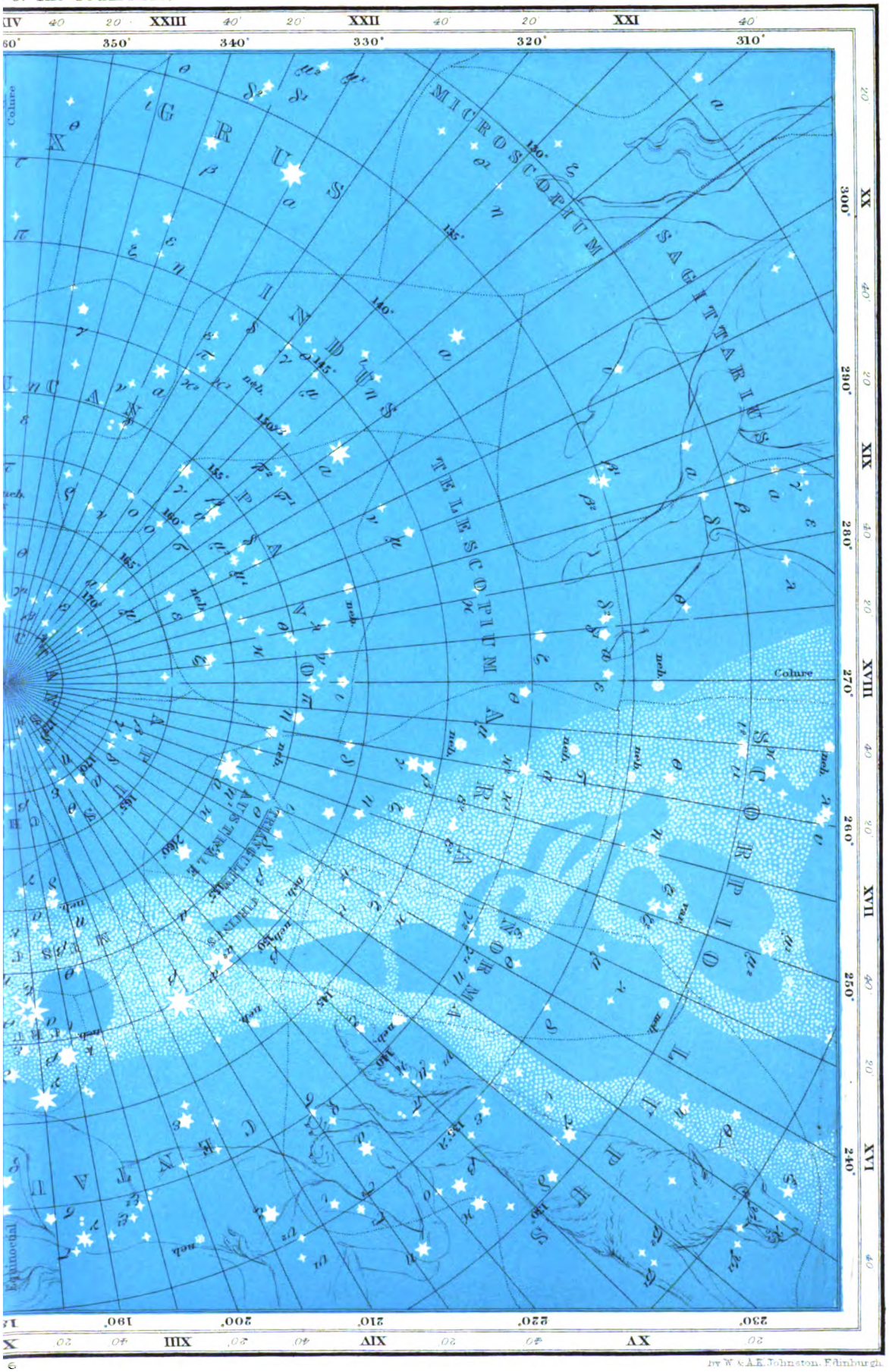

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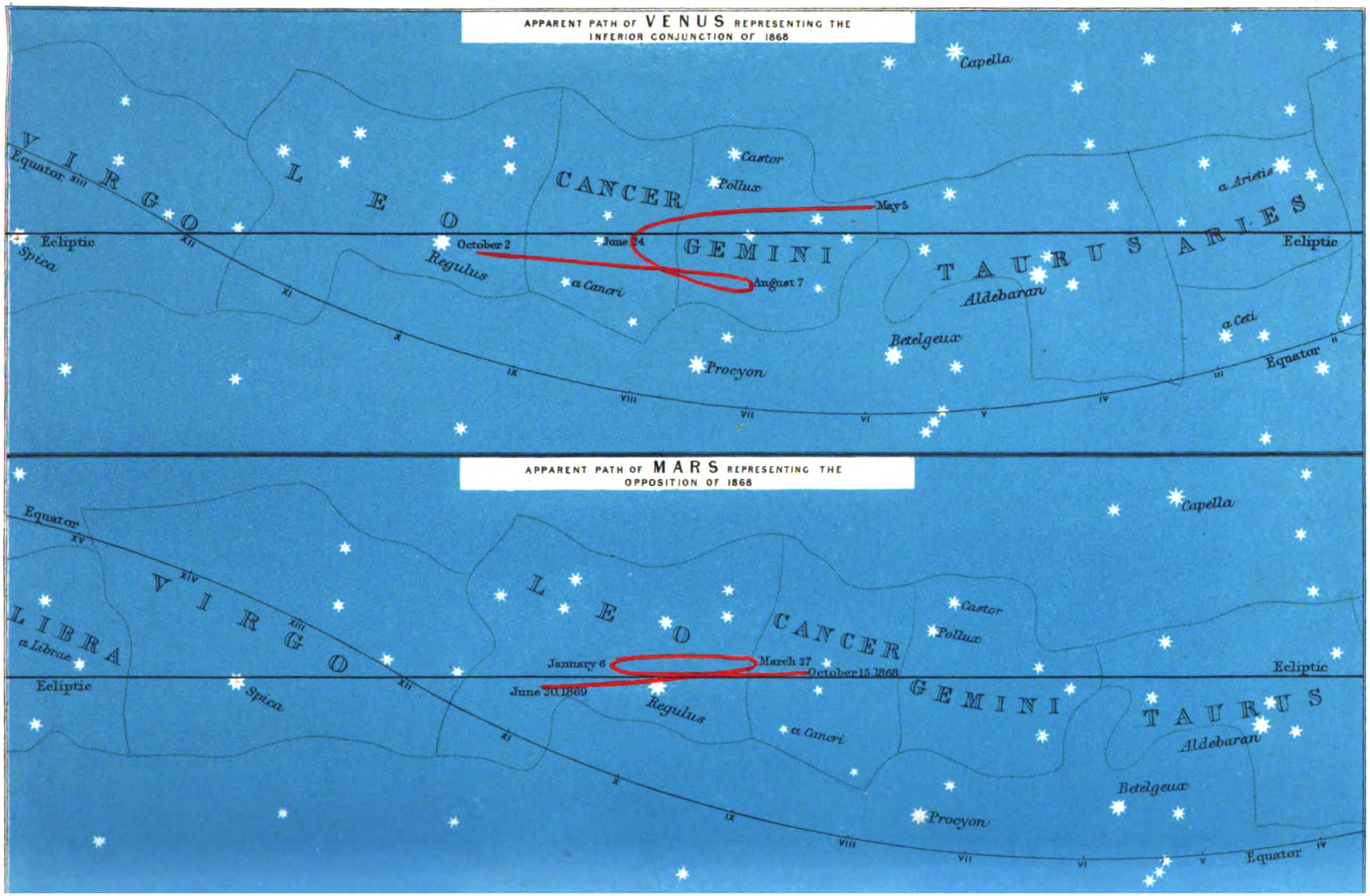

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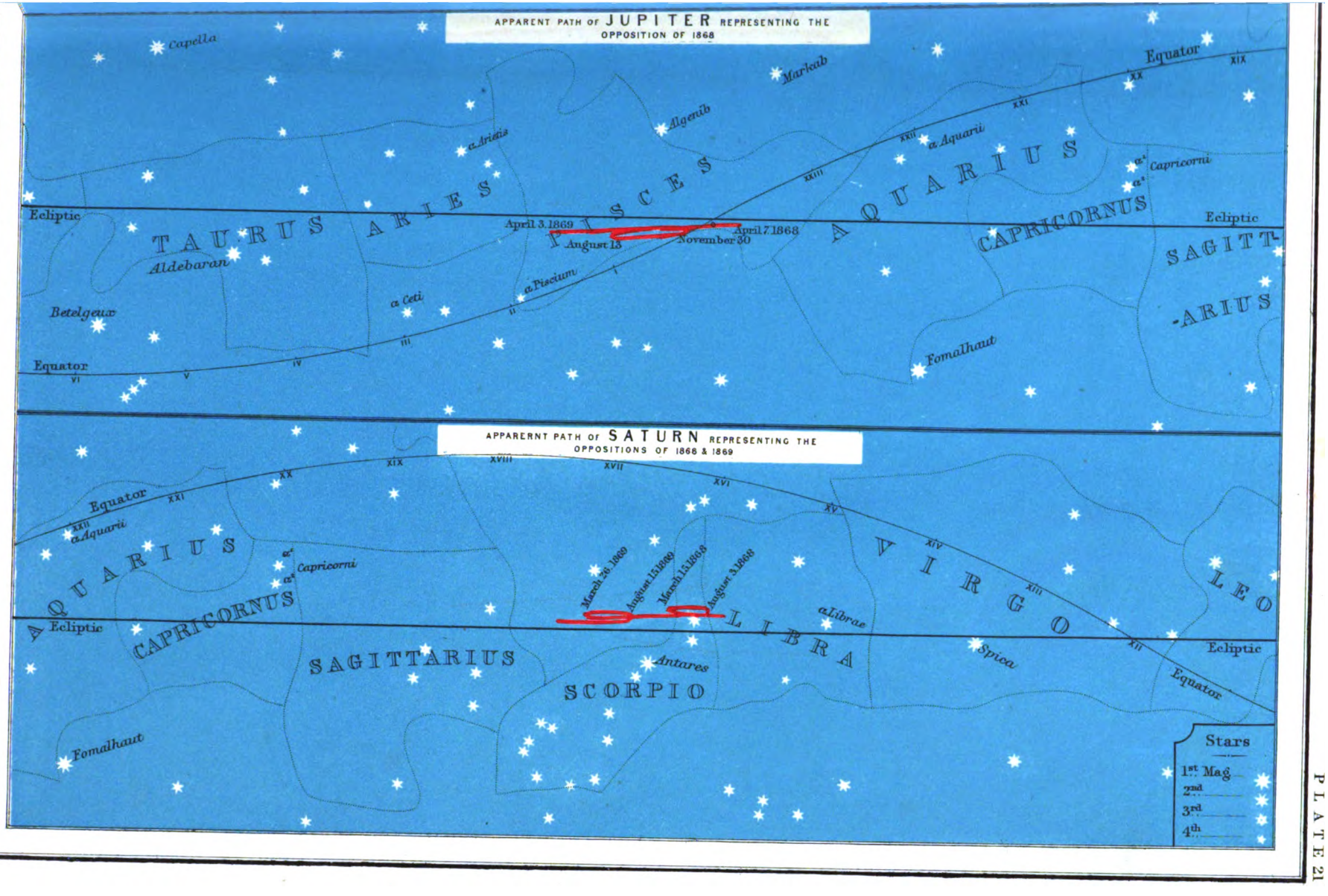

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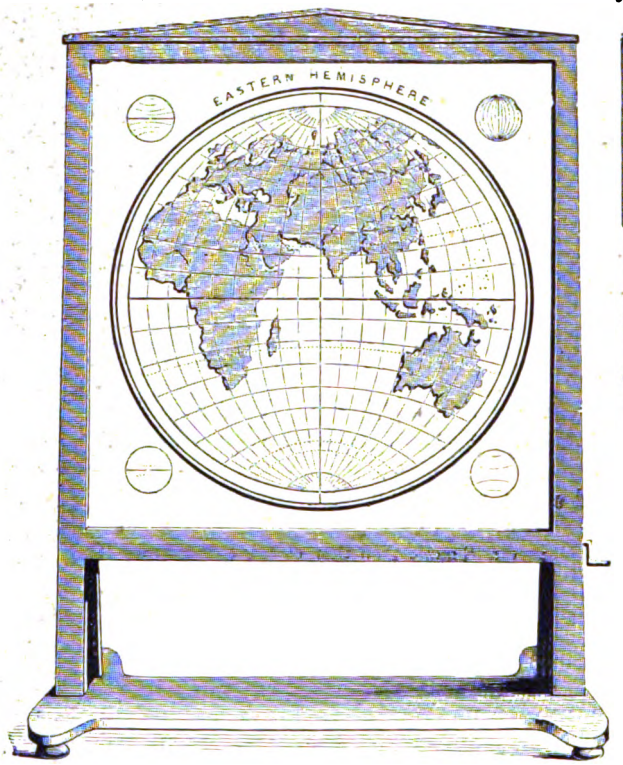

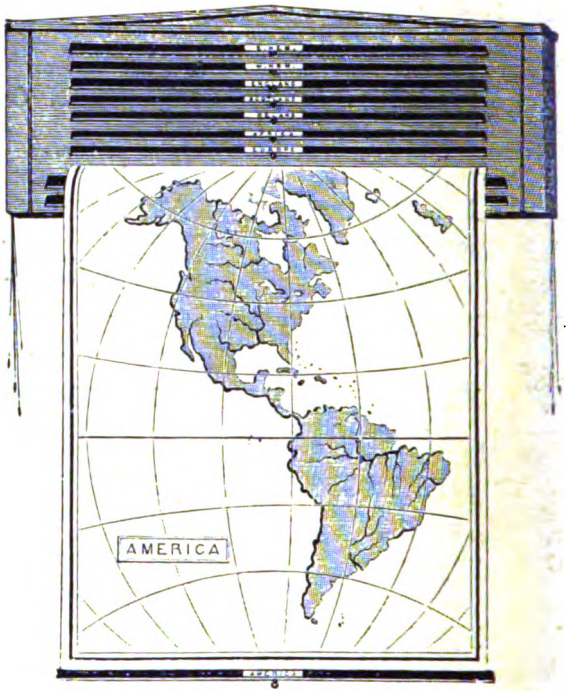

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